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9015 REPORT

FOR PERIOD

1 January to 30 June 1965

25 YEAR RE-REVIEW

SPECIAL HANDLING

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Section 1.0

INTRODUCTION

1.0 INTRODUCTION

This report describes the work done on the 9015 project from 1 January 1965 to 30 June 1965. This program is a continuation of a five year project to build, improve, and operate an optical correlator as a ground data processing device. The major portion of the project is described in two reports*, it will be assumed that the reader is familiar with the program and/or has access to those reports.

Much of the effort in 1965 has been concerned with the problem of stray light and noise in the output. There are many problems that have been considered in the past, but most can be solved only in a new Processor (reference Section 7 and 9 of the Project Final Report). Also the noise problem will be basically more serious in new correlators because of the nature of laser light. Further information was required before an improvement in a next generation processor could be predicted with confidence, and hence most of Itek's effort was devoted to this problem. Most of this work was done on the experimental correlator at Itek in Massachusetts and is reported in Sections 2 and 3. The recommended application to reducing stray light in the existing Processor is discussed in Section 4.

The second problem that received considerable attention is the data film

*Model 9015 Processor Final Report, May 1964 (Itek No. SHC64-9015-310) and Project 9015 Final Report, June 1965 (Itek No. SHC65-9015-314/1 and 2). Progress reports and other documents are listed in Appendix I of the latter report.

sensitometry. The response linearity has been of interest since the beginning of the 9015 program, and new knowledge about the system has reopened the general question. In addition, the overall system is now to the point where useful film granularity and noise information can be used. For that reason, a study was conducted by our photography department. Their results and conclusions are included as Section 5 and the Appendix.

In addition to the above major efforts, Itek has assisted the field personnel and Westinghouse engineers in their work to use and improve the Processor. A description of the Processor was presented to a number of Westinghouse personnel. Itek also assisted [redacted] personnel in work with the STAT 9015 bench correlator and other facilities. During this period the 250 page, 2 volume, 9015 Project Report was completed and published.

Recently Itek has submitted a proposal (Itek No. SHC65-9015-295) to continue the program. This includes work on the significance of noise in the correlation process and the further investigation of film reversal techniques.

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Section 2.0

REDUCTION AND ELIMINATION OF THE SOURCES OF STRAY LIGHT AND NOISE

2.0 REDUCTION AND ELIMINATION OF THE SOURCES OF STRAY LIGHT AND NOISE

In this section a variety of methods of reducing and eliminating both stray light and noise will be discussed. There are five important sources of stray light in the correlator:

(1) Accumulations of dust particles and vapor condensations on the surfaces of glass elements.

(2) Dust particles and other contaminations in the platen liquid.

(3) Scratches and abrasions on the glass surfaces.

(4) Secondary reflections from the glass surfaces.

(5) Reflections from metal surfaces within the relay lens (i. e. the jaws of the stops and the baffling).

And there are two sources of statistically invariant, mathematically describable noise:

(6) Input film granularity.

(7) Laser speckle noise.

At the output it is sometimes difficult to distinguish between stray light and noise. The noise appears as a spread of light, while the stray light appears as either a spread or, more often, as a group of distinct patterns. Moreover, the noise tends to be constant over the whole area of the output, while the distribution of the stray light varies immensely. For these reasons the

two types of phenomena have been treated separately.

2.1 Accumulations of dust particles and vapor condensations on glass surfaces proved to be troublesome sources of stray light. One must in some fashion clean the surfaces in order to remove any contamination present, although too frequent cleaning leads to an unhappy result: abrasion of the surfaces. The old (and unsatisfactory) cleaning method involved the use of methyl alcohol and Kleenex tissue. Alcohol was poured on the tissue from the bottle, the sopping tissue was rubbed on the glass surface, and the liquid was wiped dry with another tissue. Always a deposit remained, and always this deposit attracted yet more contamination. It was reasoned that the alcohol had become impure from the backflow into the bottle, so a special polyethylene dispenser was obtained. This eliminated the backflow, but did not eliminate the problem.

Professional assistance was summoned. Methyl alcohol and Kleenex were indeed the correct materials, but the method of application was wrong. Contrary to previous suspicions the alcohol itself was not the contaminating agent; the culprit was the <u>evaporation drying</u>, which collected dust and vapor from the air, which in turn collected more dust and vapor. The new method recommended by the Itek Optics Department consisted of the following:

(1) Fold a Kleenex tissue to a 2" x 2" square.

(2) Hold it so that only one straight edge is the cleaning edge.

(3) Apply alcohol to the tissue.

(4) Wipe it successively <u>and slowly</u> across the surface, such that the evaporation trail of

the alcohol is barely visible after the trailing edge of the tissue.

(5) Repeat if contamination was heavy.

This procedure not only cleans the surfaces thoroughly the first time, but also, if done correctly, ensures that the surfaces will remain clean for several days.

An Effa compressed-freon duster was helpful in blowing away the slight overnight dust accumulation.

2.2 The problem of contamination in the platen liquid had a single obvious solution: filtration. A pump and filtering apparatus were purchased from the Millipore Corporation. The filter is capable of eliminating all particles larger than 0.8 micron with a flow rate of 3 gallons/minute. (It is also possible, of course, to remove foreign liquids that may be in the tetrachloroethylene, but the cost would be unwarrented considering the probably minuscule amount of liquid contamination present.) The pump and filter are pictured in Fig. 2-1, and the platen and hose connections in Fig. 2-2.

2.3 Despite careful attention, scratches and abrasions on the glass surfaces have come to contribute some amount of stray light, since the optics have been in use for two to four years. (The new cleaning method outlined in Section 2.1 should reduce abrasions in the future.) The only way to remove the blemishes is to repolish the surfaces. This was not done because repolishing is an expensive and time-consuming proposition.

Only the verticle components of scratches cause great difficulty, for they spread the light horizontally, and the 8:1 azimuth compression assures that much of this light will be reimaged. For this reason some of the very worst

Figure 2-1: The Pump and Filtration Apparatus

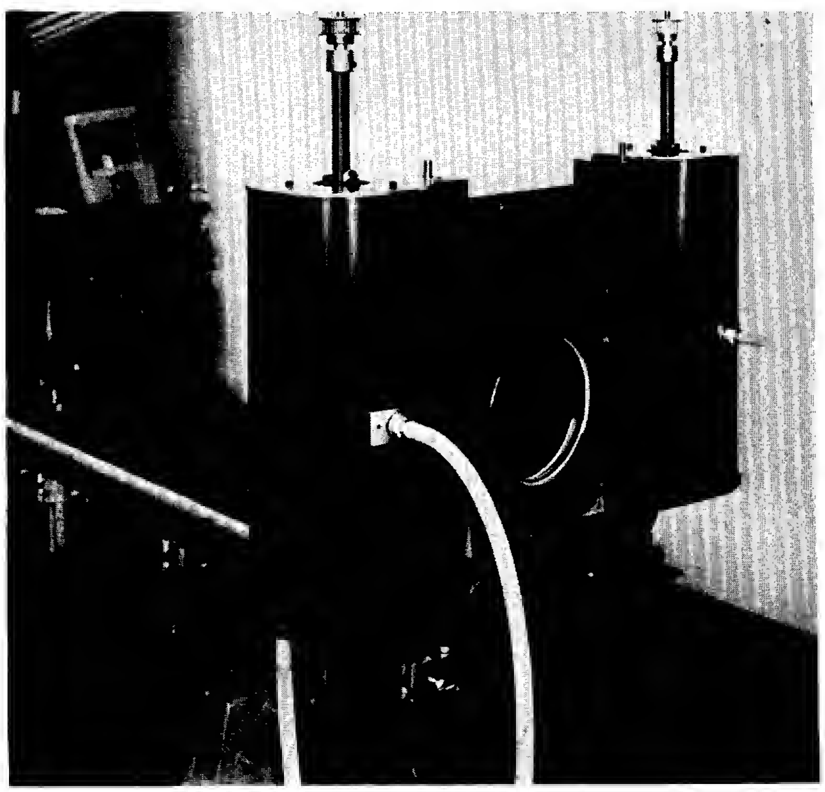


Figure 2-2: The Liquid Platen with Hoses Attached. The bottom hose is for drainage.

scratches contribute little stray light. These scratches are entirely horizontal, and are found on the inside surfaces of the platen where the data film dragged particles of matter with it through the gate. The filtration should in the future remove all such damaging particles.

2.4 Almost from the outset of the 9015 program it had been realized that air-glass interface reflections would be a major source of stray light. Unfortunately the radii of the lens surfaces were not chosen with suppression of reflections as an important parameter. Two years ago the positions of 153 secondary reflection images were determined, and their intensities calculated*. These calculations led to a final theoretical ratio of 96:1000000, reflected light to incident light. Considering that the intensity of information-bearing light is only approximately 2500:1000000, the amount of reflected light is quite significant.

The best way to eliminate the secondary reflections is to redesign the system by using a program which will minimize the reflections. This would be a major effort, and was not within the scope of the program.

2.4.1 The most offensive lens is the element of the relay lens immedialy before the zero-stop. Because of the high concentration of the zero order light at that point the reflections are very strong. And because some light that is reflected off the jaw of the zero-stop is immediately re-reflected by the back surface of the lens, the lens is doubly offensive. Some of the inside reflections can be eliminated by placing absorbant material on that portion of the backside of the lens which does not admit any light (see Fig. 2-3). Care must be taken not to stop out the information-bearing light, since it diverges somewhat from the zero order. Furthermore, the verticle

*See 9015 Project Final Report, Section 7.8 and Appendix IX.

aperture must not be so small as to impair range resolution.

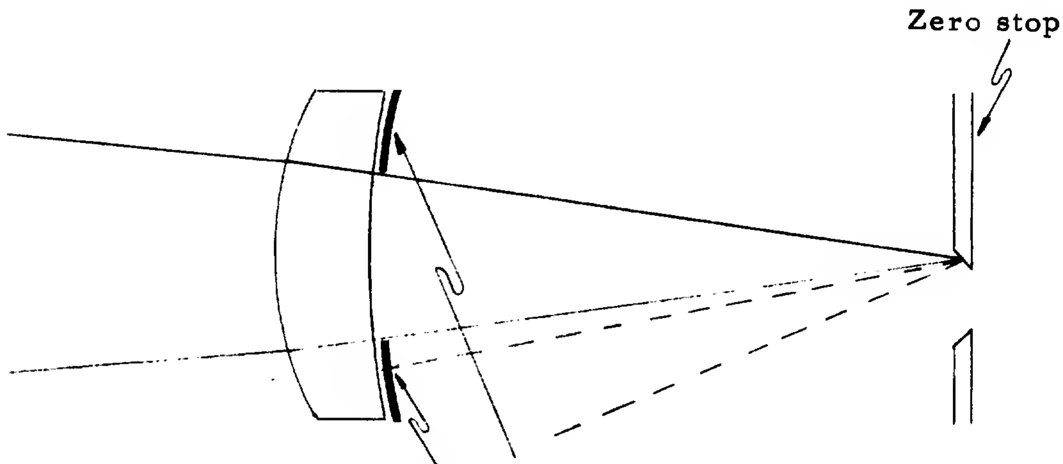


Figure 2-3: Masking the Relay Lens

2.4.2 Another possible means of suppression utilizes the linear polarization of the laser output. By the judicious use of polarizing materials one can filter the reflections and let the main beam pass.

This effect can be had by using linear and quarter-wave plates. A $\frac{1}{4}$-wave plate has the effect of converting linearly-polarized light to elliptically-polarized light, the eccentricity of the ellipse depending upon the orientation of the $\frac{1}{4}$-wave plate. Passing twice through a $\frac{1}{4}$-wave plate is the same as pssing once through a $\frac{1}{2}$ wave plate: the polarization angle is shifted by 90°.

Consider now the arrangement of Fig. 2-4. Assume the laser polarization is vertical and that plate B is a vertical linear plate. As the light wave moves through plate A the polarization angle becomes 45°, producing circular polarization. This is the light which passes on through the system to become correlated. The reflected light, however, passes back through plate A and the angle of polarization is once again moved 45°, so that it is

now displaced 90° from that of the source light — and from filter B. The reflected light will be absorbed.

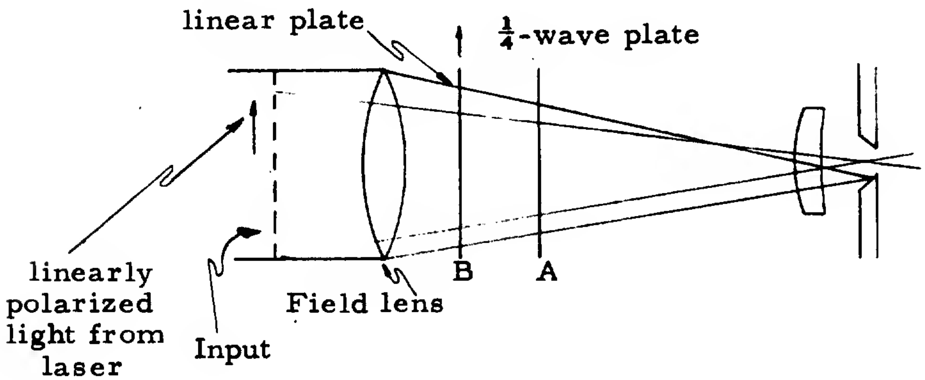


Figure 2-4: Filtering Secondary Reflections by Polarization

Other arrangements are possible, and several ought to be tested in order to determine which is the most effective. It may happen though, that the image degradation caused by the insertion of the polarizing materials would annul the improvement in the signal/noise ratio. Only experiment will tell.

2.4.3 Yet another way of reducing (or at least adjusting) the secondary reflections is by moving the light source. The positioning of the reflections is critical, and their effects at the output can be increased or reduced by slight adjustments in the position of the light source. Of course the various lenses, and the platen, might also be adjusted to minimize reflections, but they are secured rather solidly on the bench riders. The light source is, practically speaking, the only movable component.

2.4.4 One last way of reducing reflections remains to be discussed. Since the information-bearing light is displaced from the zero-order beam, all optics from the relay-lens on could be placed on the axis of the signal light, as in Fig. 2-5. This would mean that only one squint of the film,

virtual or real, could optimally be used. It would, in compensation, tend to reduce reflections between the relay lens and the field lens.

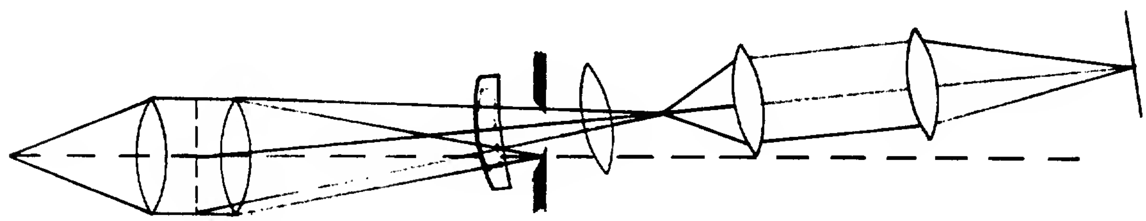


Figure 2-5: Correlator with Offset Angle

2.5 Reflections from metal surfaces within the relay lens contribute an unascertained, but nonetheless present, amount of stray light. The zero-order is several orders of magnitude greater than the information-bearing light, so baffling and containing it present a difficult problem. The jaws of the stops are black mirrors which absorb some light and specularly reflect the remainder. The reflected portion is captured by matte black baffling, which does, however, re-reflect some of the light.

The best way to deal with these reflections is shown in Fig. 2-6. Currently the baffling presents a dull edge and scatters a fair amount of light.

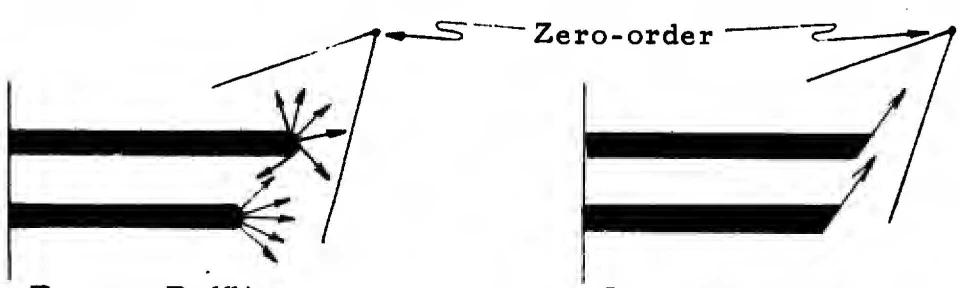


Figure 2-6: Improving the Baffling

If the edges were sharpened they would present much smaller surfaces to the source of reflected light, and consequently scatter much less.

The jaws themselves present a further problem. The reflected portion of the light (which is still two or three orders or magnitude greater than the information light) is not necessarily reflected onto the baffling. As in Fig. 2-7, the relative positions of the components might well be such as to cause the zero-order to impinge on the edge of the other stop. The components were designed to eliminate this reflection, but the alignment is critical, and should be closely checked.

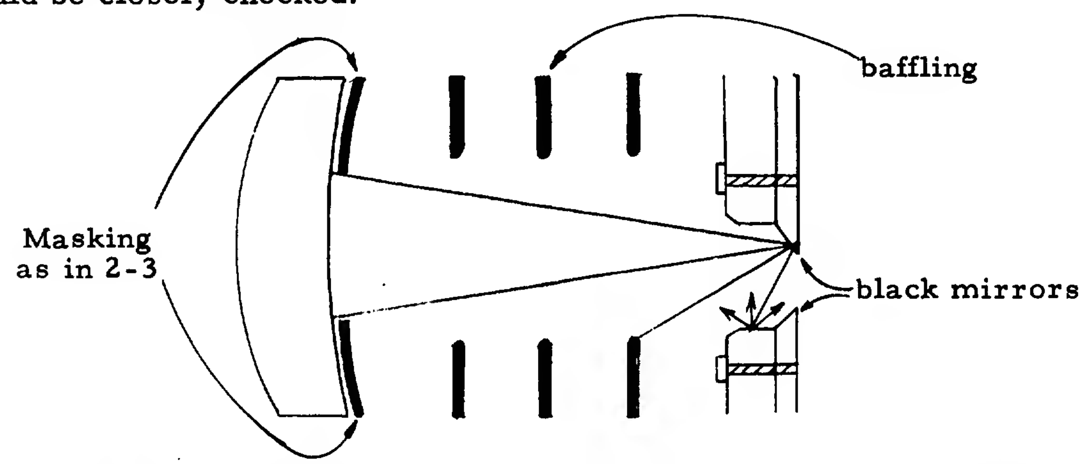


Figure 2-7: The Reflected Zero-order Impinges on the Other Stop

The surface of the black mirror is not perfect, furthermore, and small imperfections can scatter quite a bit of light. The mirror should be repolished and recoated.

2.6 Granularity of the input film is a source of noise in the system. Research on finding a better film was done, and the results are reported in a separate section. Some testing of the present film in the coherent processor was also done, and these results are reported in Section 3.6.

2.7 Another type of noise is caused by the coherent monochromatic source, and is called speckle noise. Any diffuse surface will produce this type of pattern, on either reflection or transmission. This noise gives a structure to the correlated output of the system because coherent light is additive in amplitude rather than intensity, i.e. destructive interference is possible. An article by Goldfischer[1] has elucidated the problem by giving a mathematical treatment of it. His conclusion is of importance to those engaged in coherent optical data processing: Two second-order statistics of laser-produced speckle patterns, viz., the autocorrelation function and the power-spectral-density vs. space-frequency, were shown to be affected only by the variation of incident power over the illuminated area and the observation distance. The phase distribution over the illuminated area and whether the plane of observation is in the near or far field were shown to have no effect on either of the statistics. This means that the speckle frequencies can be filtered in the same fashion that one can filter the dots from a half-tone reproduction, and achieve a more pleasing result.

No research has yet been done on this subject.

[1] Lester Goldfischer, "Autocorrelation Function and Power. Spectral Density of Laser-Produced Speckle Patterns", JOSA, Vol. 55 #3, March 1965, pp 247-253.

Section 3.0

RESULTS

3.0 RESULTS

This chapter describes the results obtained from making some of the modifications suggested in the previous section. In all cases the measuring arrangement was the same, and is shown in Fig. 3-1. The apparatus was mounted on the Improved Optical Bench as described in the 9015 Project Final Report, Section 4.2.

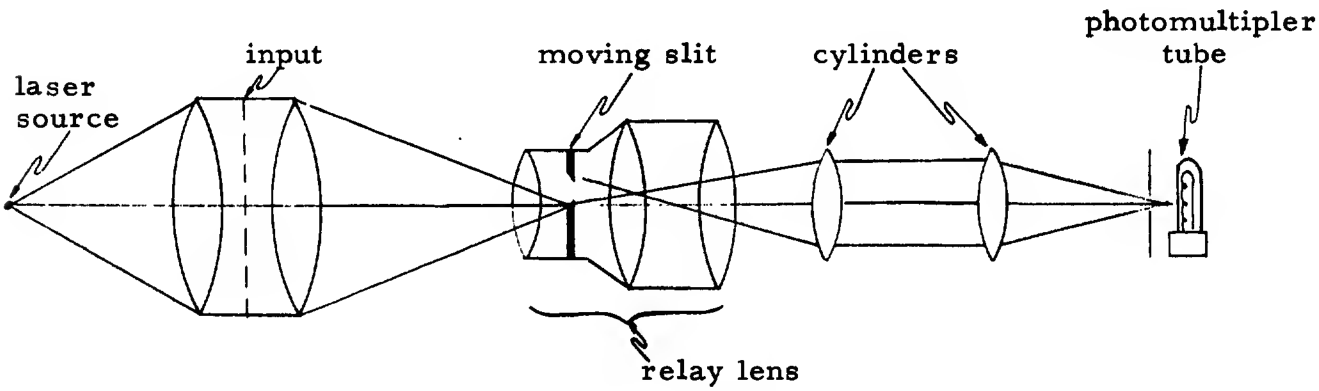


Figure 3-1: Measurement Apparatus

Light passed through the slit can be measured either directly behind the slit, or it can be imaged so that the readout is made in the spatial domain. The latter alternative offers an important advantage: separation of noise from other disturbances. In the frequency plane there appears not only the noise energy, but also, convolved with it, the transform of the source, which is diffraction-limited by the finite aperture at the input plane. In fact, these secondary maxima in the frequency plane are usually greater in intensity

than any noise one would encounter, thus obscuring measurement. Worse, the secondary maxima cannot later simply be subtracted from the noise trace of the frequency plane, for in a coherent system signals add in amplitude rather than intensity.

One way to eliminate this difficulty is to apodize the input aperture. Such a measure is, however, not easy to effect, since accurate weighted filters are difficult and expensive to make. Moreover, the filters are themselves grainy, and might well add as much noise of their own as they remove from the signal.

The best solution is also the simplest. As in Fig. 3-1 the frequency domain is transformed into a spatial domain: the secondary maxima reconstruct to form an image of the input aperture, and the noise signals reconstruct to form an image of the input film (or whatever else the input may be). If the photocell is properly placed in the center of the output it will see only the image of the film, for the image of the aperture will fall around it. Finally, the image of the input film will be formed only by the small band of frequencies passed at any moment by the slit. As the slit traverses the frequency plane the trace of the photocell reading will indeed be proportional to the energy density of noise actually present in the frequency plane.

This method also serves to measure the energy-density spectrum of data film, or of any other input one may choose.

The moving slit was fashioned from the stops already in the frequency plane. Originally each stop was moved by its own micrometer; for these experiments a shim was placed between the stops, and one of the micrometers was disengaged. Thus one micrometer moved both jaws together at a constant

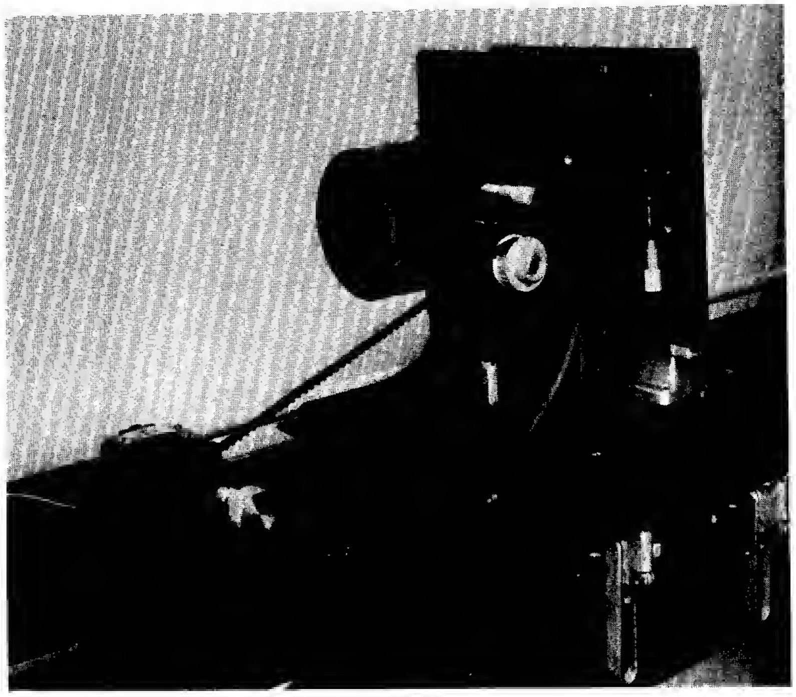


Figure 3-2(a): Slit Drive Mechanism

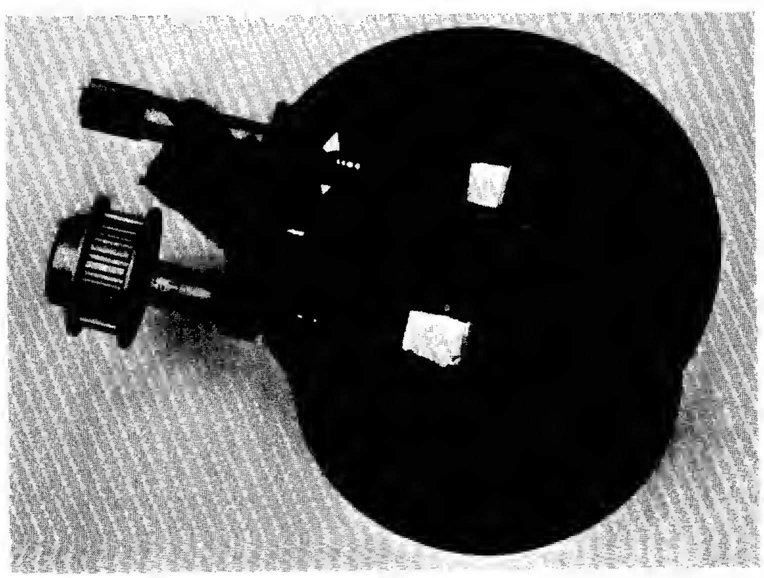


Figure 3-2(b): Interior View of Relay Lens, Showing Shims Placed Between the Jaws of the Stops

separation across the frequency plane. The apparatus is pictured in Fig. 3-2. The micrometer which moves the slit is driven by an accurate, stable timing motor. The output of the photocell is fed into an amplifier with meter, which has an input sensitivity range of 1000:1. The output of this device feeds a Varian chart recorder for a permanent record. The slit moves, in all, approximately four-tenths of an inch (i.e. $\pm$ 350 cy/in). The length of the trace on the chart paper is approximately four inches, and is of the general shape of Fig. 3-3. The dashed lines on either side represent the average noise levels, which are computed for a bandwidth of 65 to 300 cycles/inch. An average noise level of 10 units is referred to a zero-order level of 100000 units.

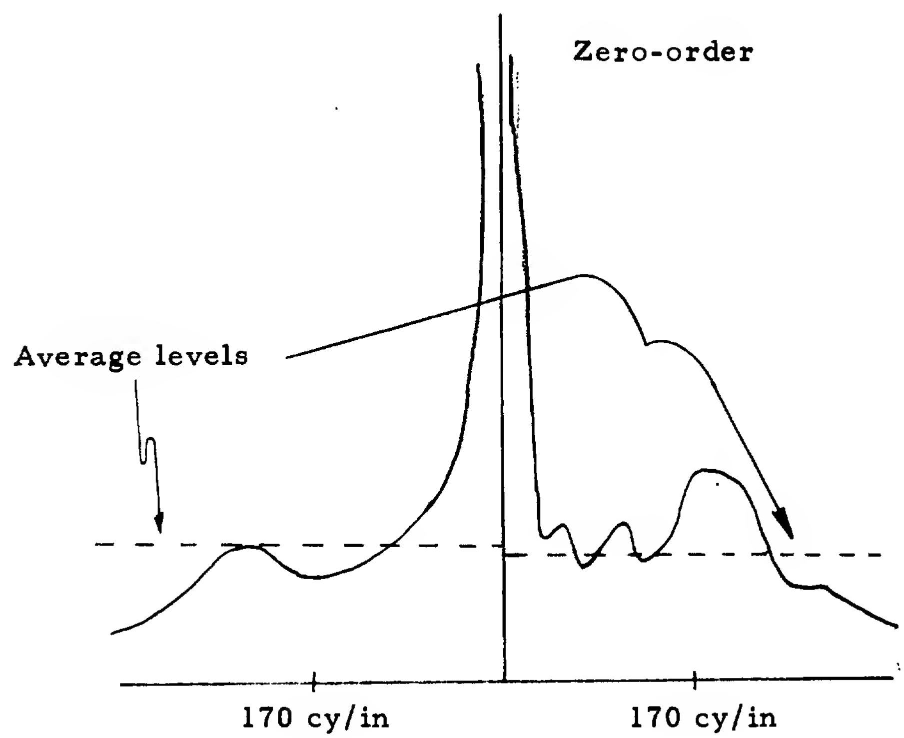


Figure 3-3: Typical Trace of Frequency Plane

3.1 Results of Properly Cleaning the Glass Surfaces

Figure 3-4 shows a typical noise trace of the system before the glass surfaces were cleaned. Figure 3-5 shows a noise trace after the surfaces were cleaned by the "old" method described in Section 2.1, and Fig. 3-6 shows a trace after the surfaces were cleaned by the "new" method. The table below gives a numerical comparison. Since the traces of the system

	trace a	b
before cleaning	50	28
after "old" cleaning	28	22
after "new" cleaning	17	7
one week after "new" cleaning	18	9

Table 1: Results of Cleaning Glass Surfaces

one week after the "new" cleaning are little different from the traces taken immediately after the cleaning, they are not shown: only their average values are put in the table.

As can be deduced from the table, the "new" method of cleaning resulted in a noise improvement factor of 3 in the best case.

3.2 Results of Liquid Filtration

Installation of the pump and filtering apparatus made a significant improvement in the appearance of the fluid. No longer were there the large chunks of debris which formerly contaminated the fluid. Figure 3-7 shows a typical trace of the noise of the system before the filtration was added, and Fig. 3-8 shows a trace after it was added. The noise improvement

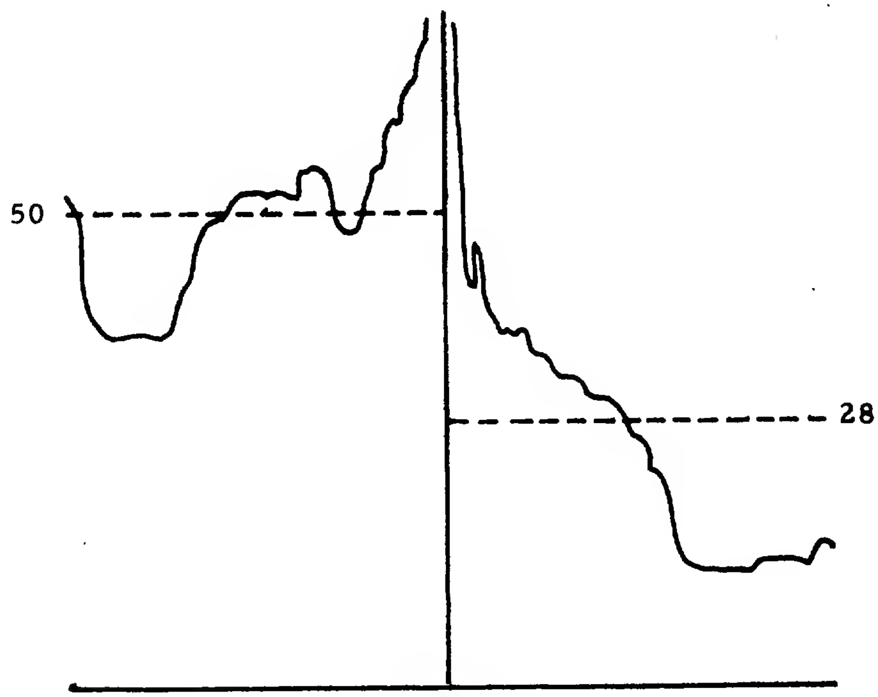


Figure 3-4: Trace of Stray Light Before Cleaning the Glass Surfaces

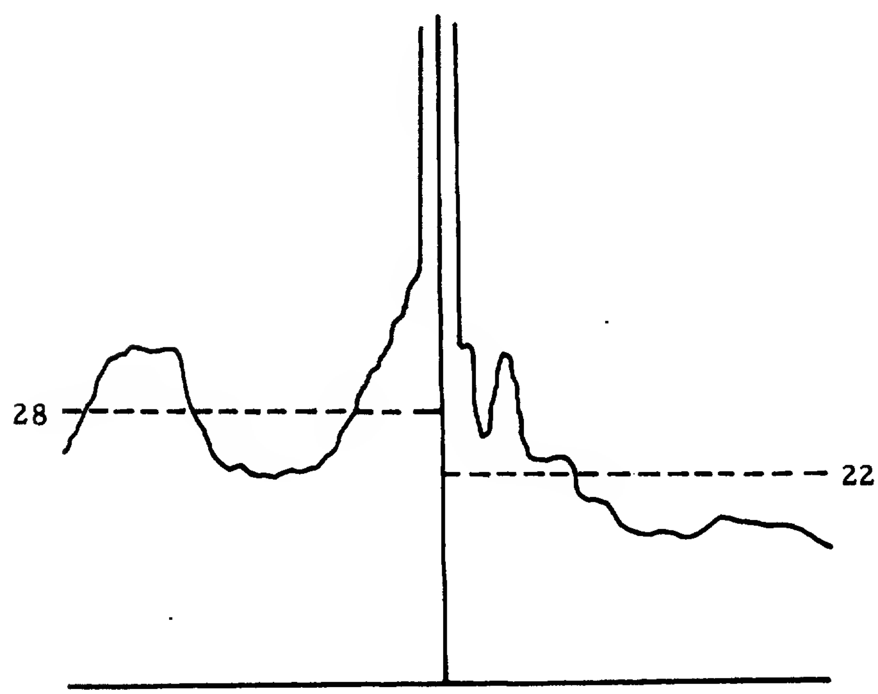


Figure 3-5: Trace of Stray Light After Applying the "Old" Cleaning Method Described in the Text

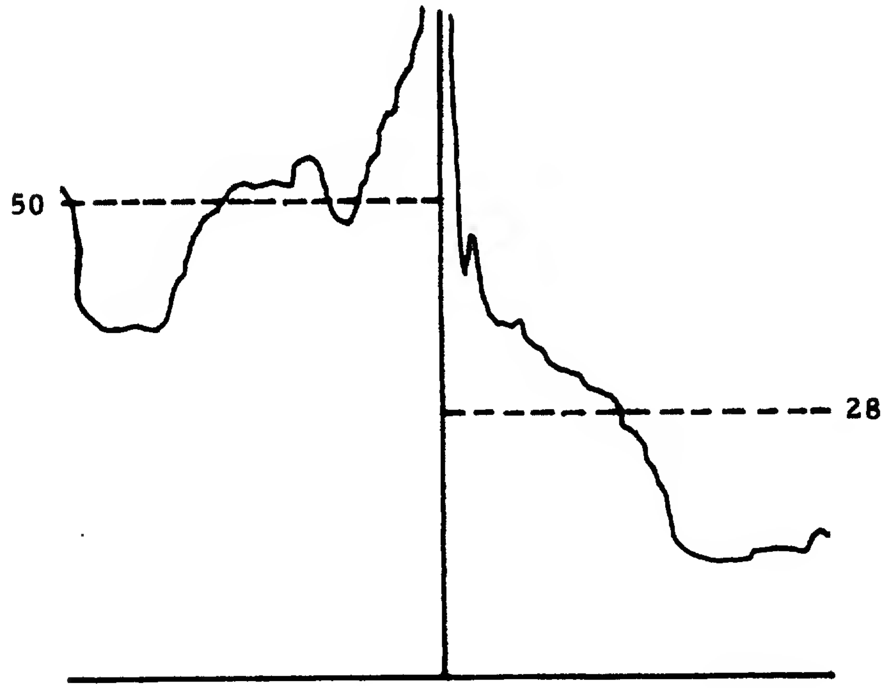


Figure 3-4: (repeated)

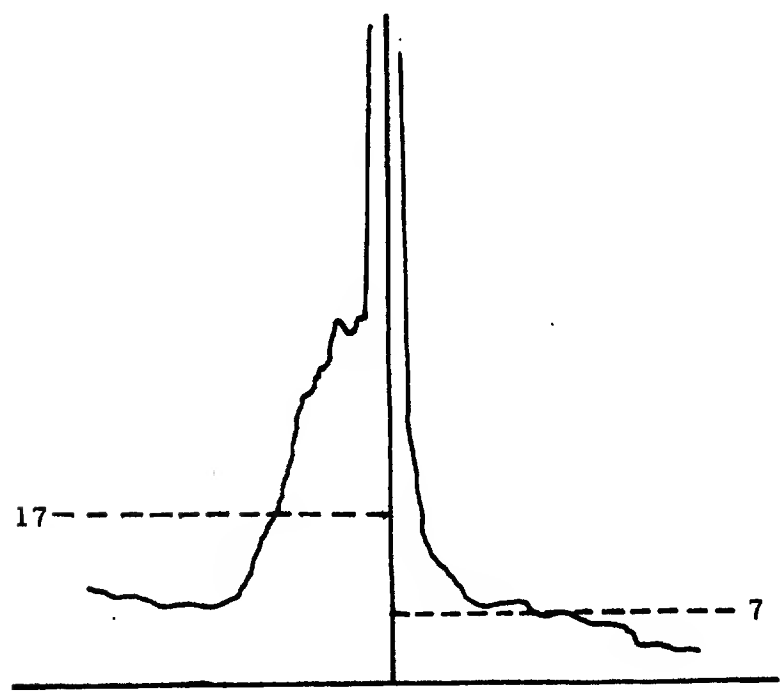


Figure 3-6: Trace of Stray Light After Applying the "New" Cleaning Method Described in the Text

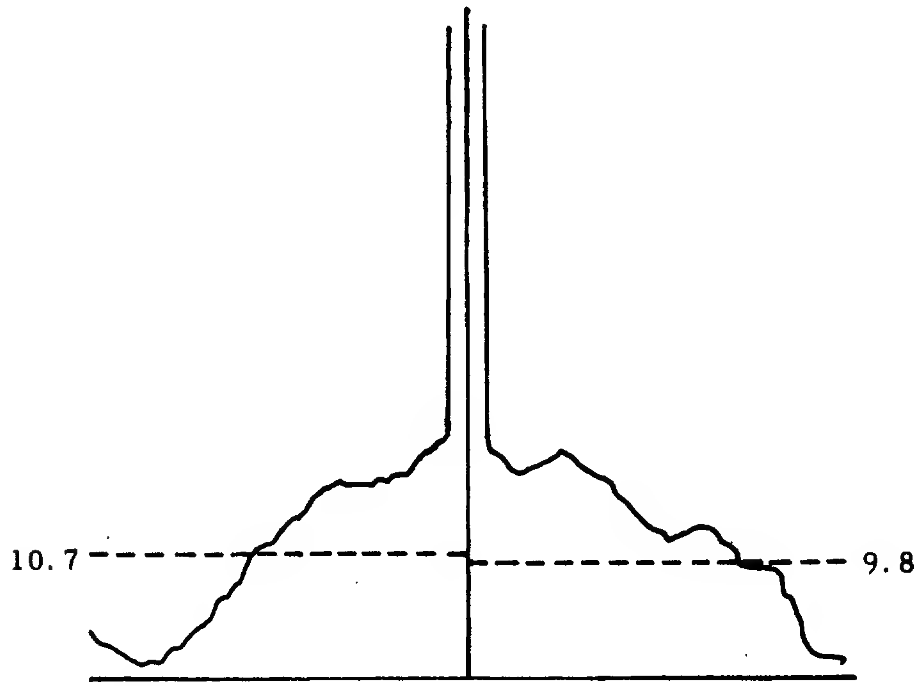


Figure 3-7: Trace of Stray Light Before Filtering the Platen Liquid

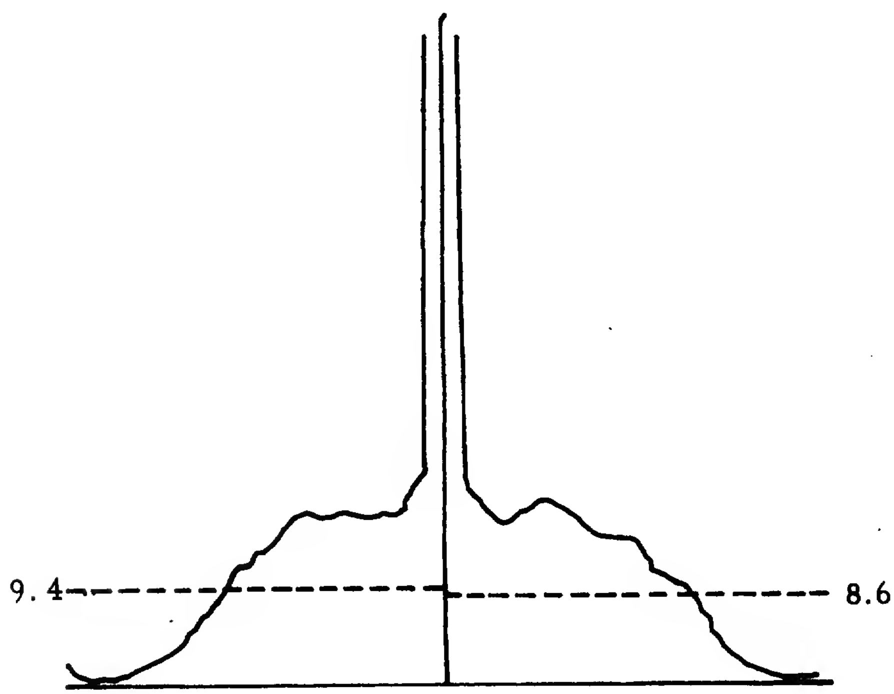


Figure 3-8: Trace of Stray Light After Filtering the Platen Liquid

factor is 1.1.

More impressive evidence of the effectiveness of the filtration can be seen in Fig. 3-9. Pictured in (a) is a clean prefilter, which filters particles as small as one-half mil. Pictured in (b) is that same filter after it had been filtering for twenty minutes. (This was the second filter ever used in the system; the first, which was in for only ten minutes, became just as dirty.) Pictured in (c) is the filter for particles as small as 0.8 micron, which was in the system with the filter in (b). The gray area is not prominent in the photograph, although it is visible on the filter itself.

A test was made to see if the system was sensitive to the flow of liquid in the tank; it was not. The noise level did not increase.

3.3 Recoating and Repolishing Glass Surfaces

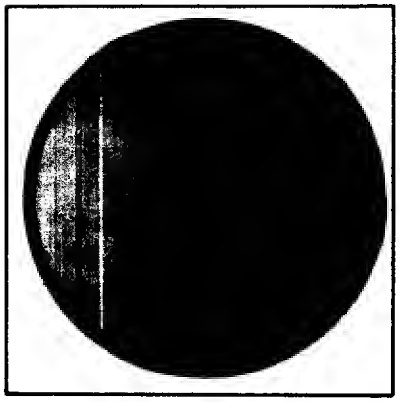
The lenses were to be repolished and recoated only if early work indicated this to be the major source of stray light. Experiments indicated this was not a major problem, so the surfaces were not refinished.

3.4 Results of Suppressing Secondary Reflections

The first suggestion made in Section 2.4 was to mask that portion of the backside of the first relay lens which does not pass the light beam (see Fig. 2-3). Although on general principles this seems a good idea, it does not measurably reduce the system noise.

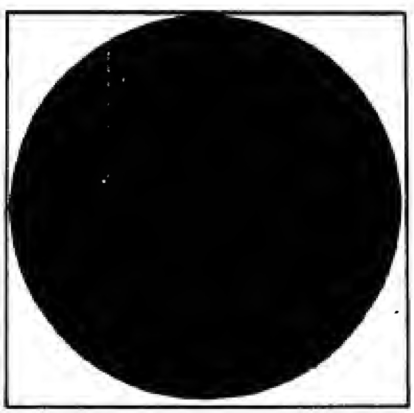
The second measure suggested was to use polarizing filters. A sample set was obtained from the Polaroid Corporation, but unfortunately they were a plastic of very low optical quality. High-quality plates should have the effects described in Section 2.4.

Careful positioning of the light source proved an effective means of



(a) Prefilter before filtering.

(b) Prefilter after filtering.



(c) Fine filter after filtering.

Figure 3-9: Pictures of the Prefilter and Fine Filter (0.8 microns) Before and After Filtering. The filters were in the system for twenty minutes, and were the second set of filters used.

lowering reflected light. It's obvious that different source positions should produce different patterns of reflection, and there is no reason to suppose that just because the source is on axis it will produce the fewest disturbing reflections. In order to measure the various positions of the laser during the test, a set of five dial indicators was mounted on the laser: one x-y set in the front, one x-y set in the back, and one z indicator on axis. (See Fig. 3-10).

The first noise measurement was made with the laser on axis, and the last was made with the laser collimated*. A variety of positions in between were measured, and the curves are shown in Fig. 3-11. The best case, as it happens, is when the laser is almost collimated, and represents a noise improvement factor of 2.3 over the worst case. Table 2 summarizes the results.

Position	Left of Axis	Right of Axis
a	17	7
b	17	12
c	8	13
d	10	10
e	12	11
f	7	8

Table 2: Summary of Stray Light Levels in Figure 3-11

Some of the more prominent secondary reflections are caused by the flat platen surfaces. An experiment was made wherein the platen was removed

*These are different positions, for the collimating lens evidently is not exactly on axis, but is somewhat tilted; or perhaps the frame which holds the lens is tilted. In either case, the mirror which is held to the frame for "collimation" is not perpendicular to the axis.

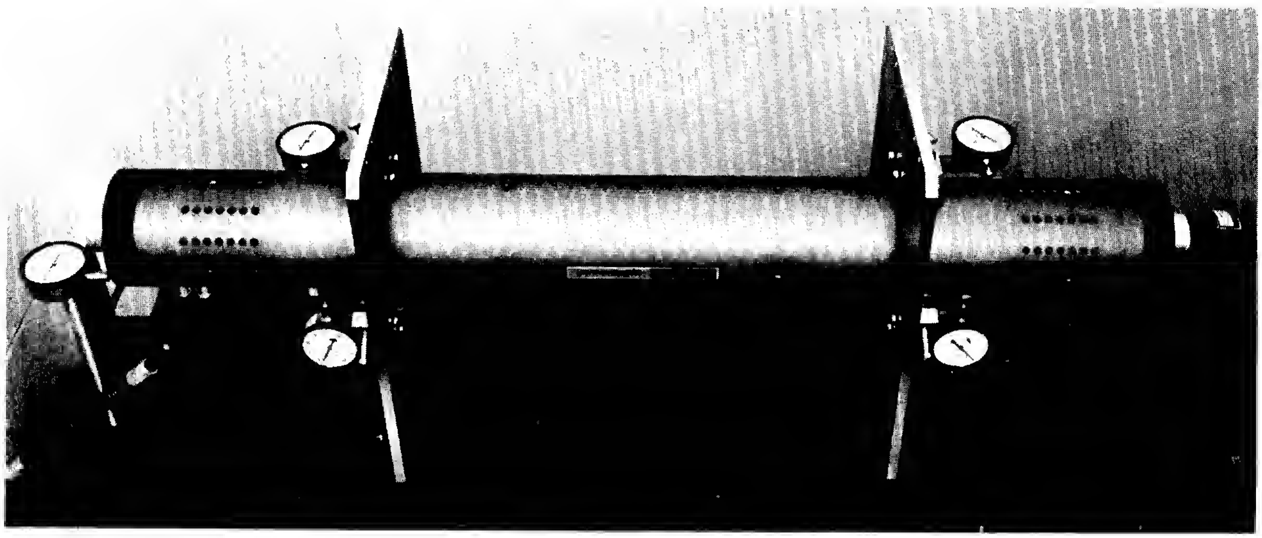
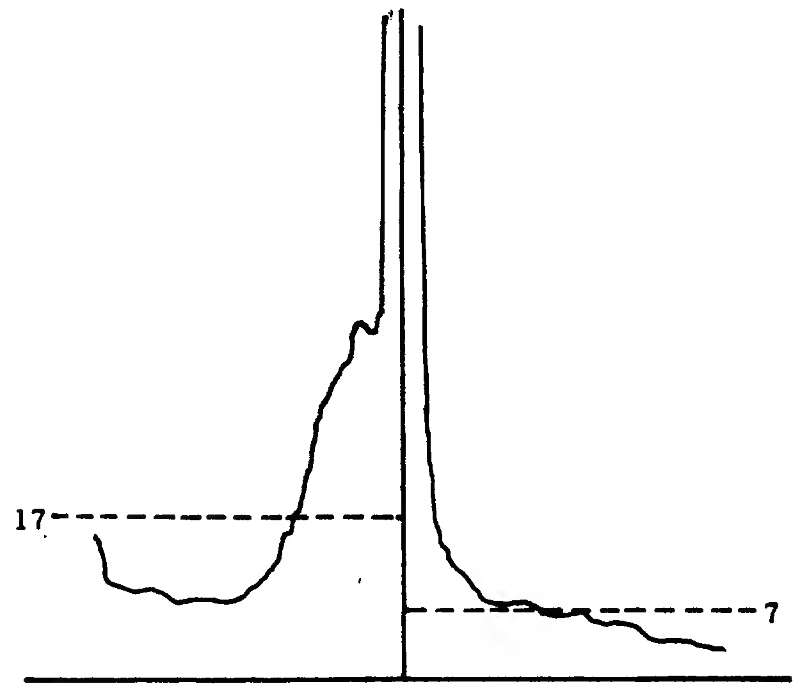
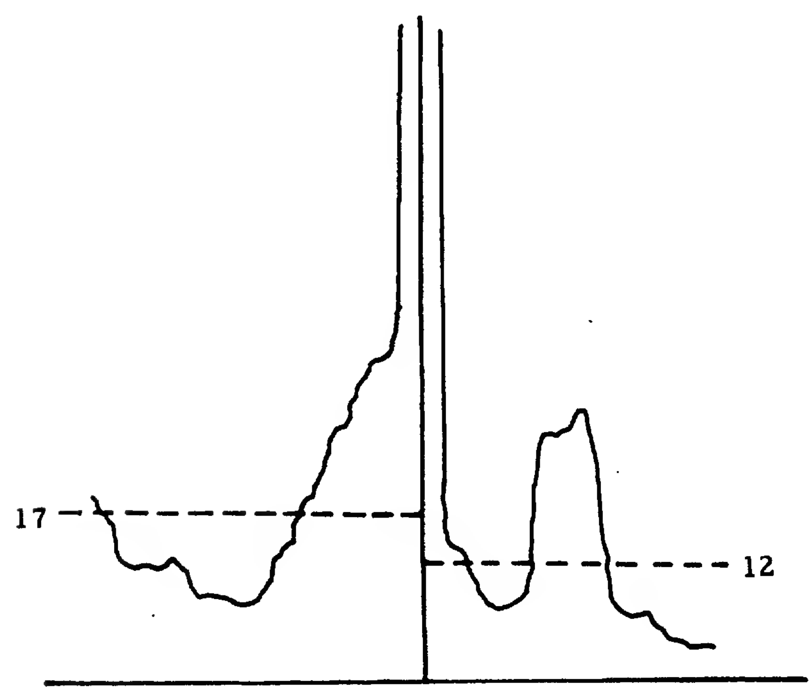


Figure 3-10: Picture of Perkin-Elmer 5300 Laser, Showing Dial Indicators Mounted so as to Measure the Position of Both Ends of the Laser

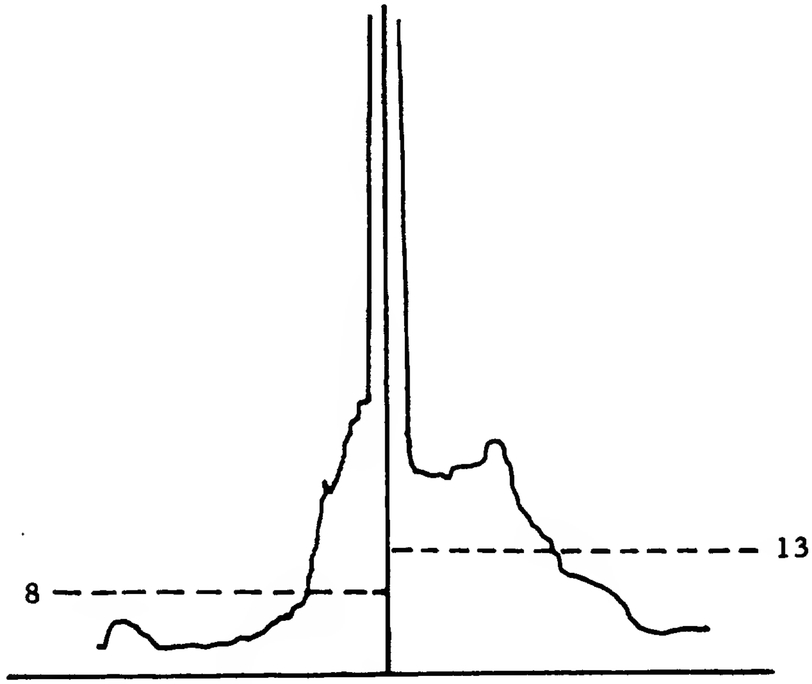


(a) Beginning position: laser measured to be on axis.

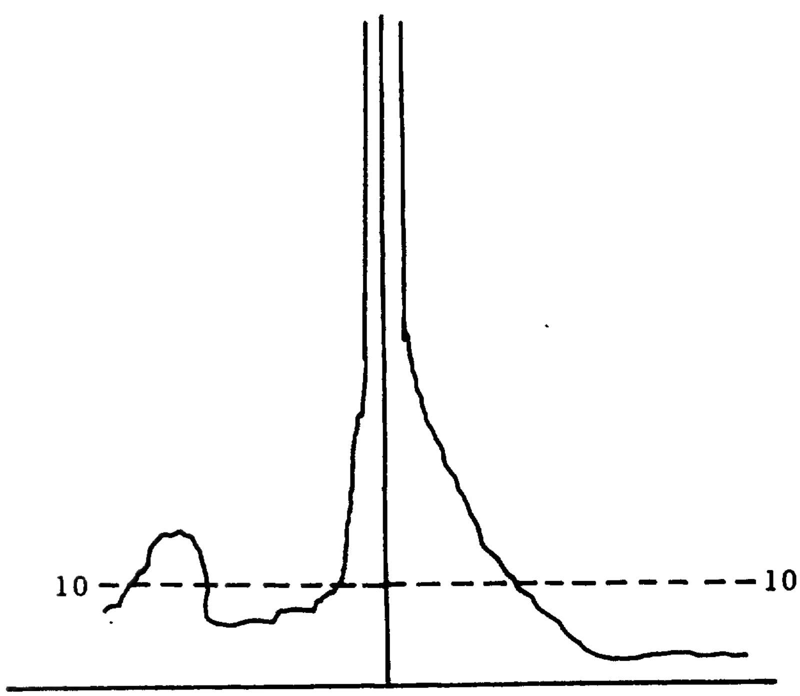


(b) Slightly displaced.

Figure 3-11: Showing What Happens as the Light Source is Moved About

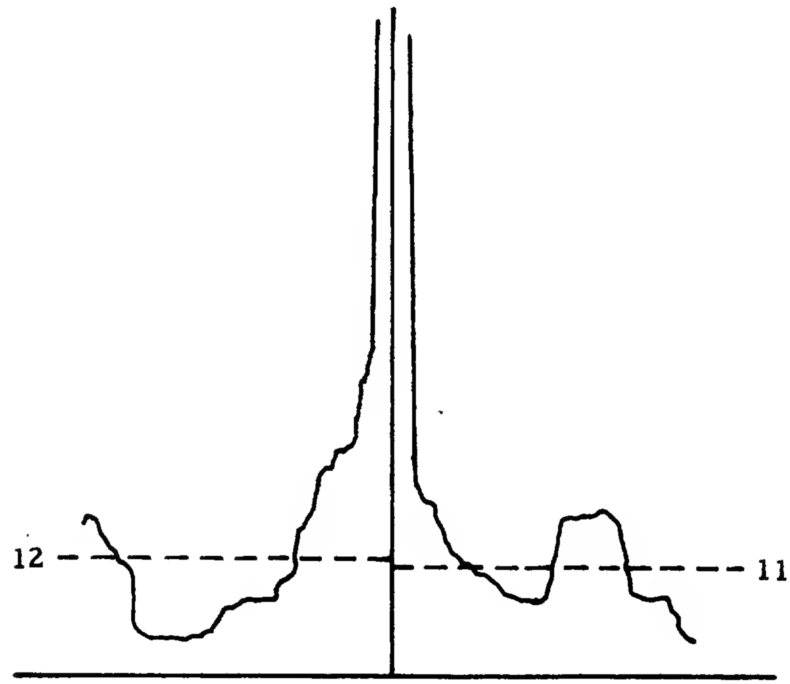


(c) Laser displaced.

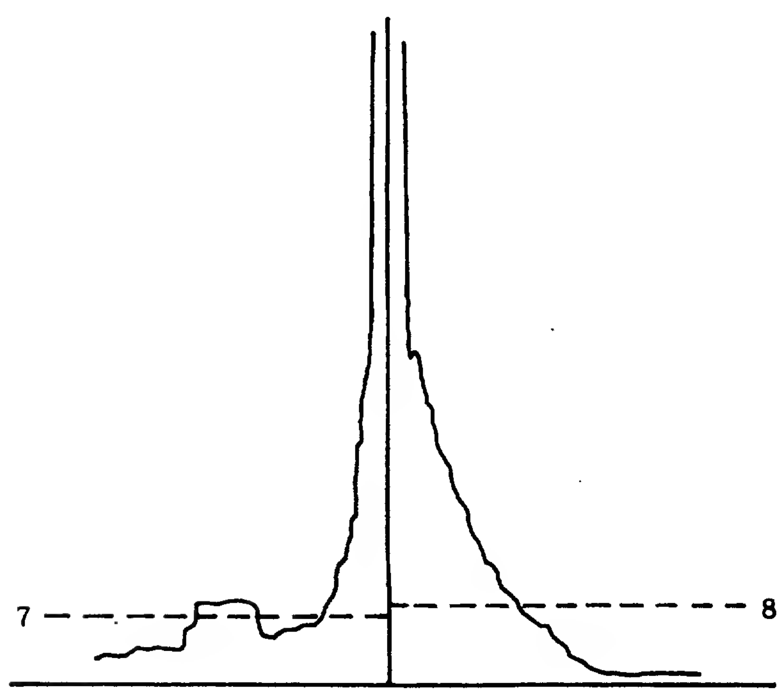


(d) Laser displaced.

Figure 3-11: (cont'd)



(e) Laser displaced.



(f) Laser collimated as explained in text.

Figure 3-11: (cont'd)

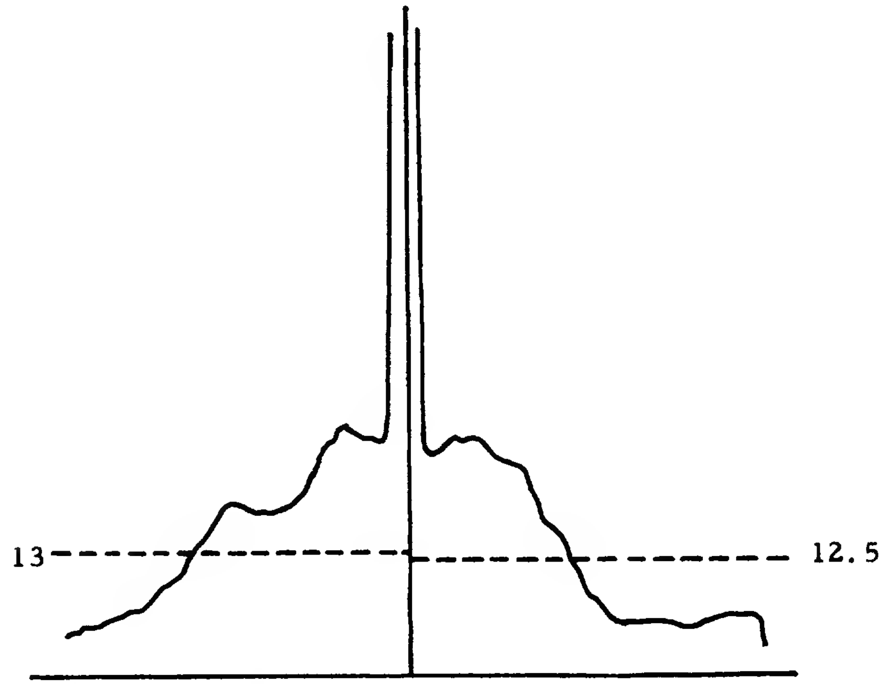
and the noise measured. Traces are shown in Fig. 3-12. Since the liquid was clean from the filtration, one can assume that the noise reduction occurred because of the loss of the four reflecting surfaces.

A dramatic change occurred when the first element of the relay lens was removed. The deleterious effects of this lens were described in Section 2.4, and experiments confirmed the descriptions. (Recall that the lens is not only the major source of secondary reflections, but that it also acts as a scatterer of light, the concentration of which light is all the greater for its being immediately in front of the zero-stop.) Without the added power of this lens, the relay unit had to be refocused so that the zero-order would focus at the plane in which the stops were located. The effect of this was to change the aspect ratio but not the signal-to-noise ratio.

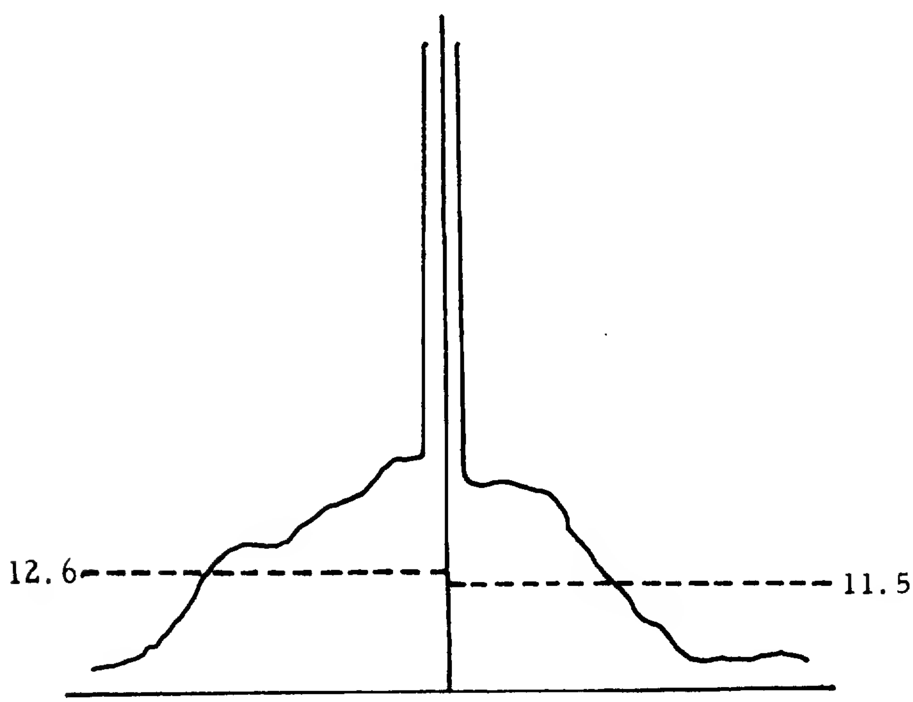
The results are shown in Fig. 3-13. By eye the change was even more impressive, for the blotches of light caused by secondary reflections disappeared almost completely. The improvement factor was 4.

Two photographs were taken to demonstrate secondary reflections. The unmagnified correlator output, about 1" wide and 8" high, has a high concentration of noise from the secondary reflections. Figure 3-14 is a photograph taken at this output. The rectangles of light, and the horizontal blotches, come from secondary reflections which are near their plane of focus. (The horizontal distensions are caused by the cylinder lenses.) The larger spreads of light come from secondary reflections which focus further back in the system. Moving the output along the axis shows the reflections passing in and out of focus.

Figure 3-15 is a photograph, taken off-axis, which shows the many

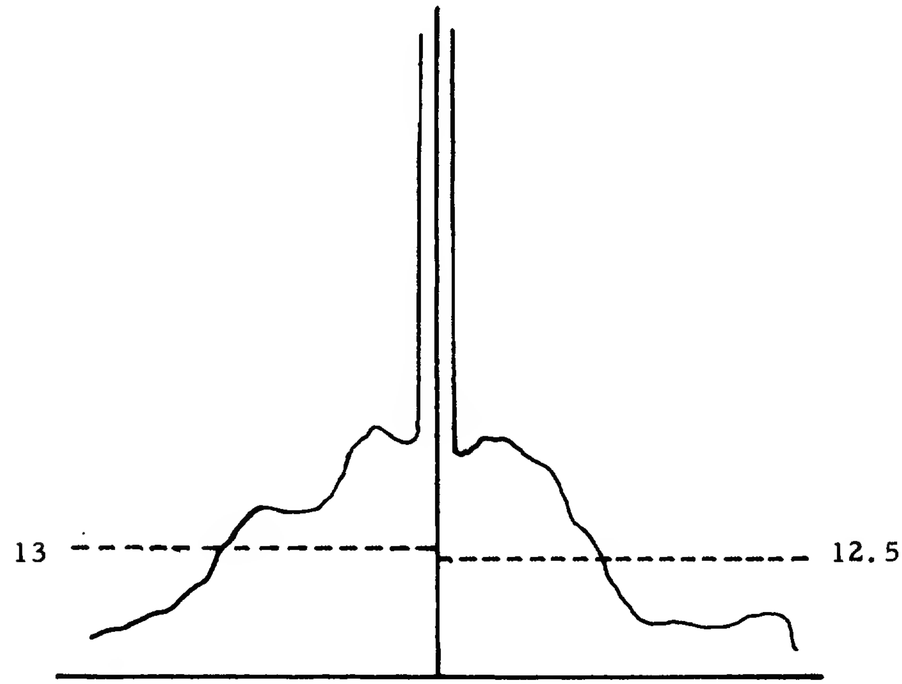


(a) Trace of stray light before removing platen.

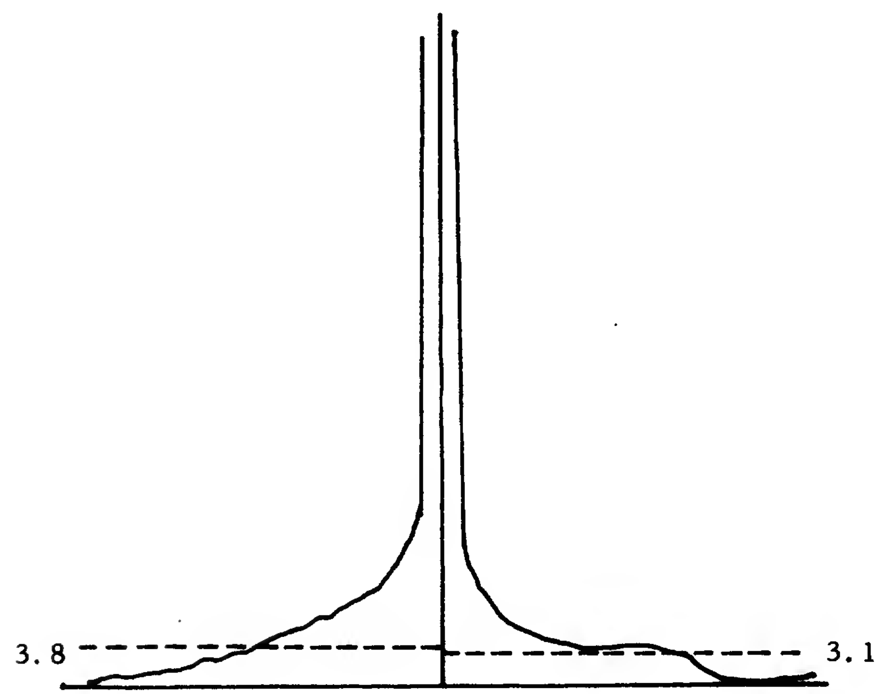


(b) Trace of stray light after removing platen.

Figure 3-12: Results of Removing Platen, in an Effort to Eliminate Some Secondary Reflections.



(a) Trace of stray light before removing first element of relay lens.



(b) After removing lens.

Figure 3-13: Results of Removing First Element of Relay Lens

Figure 3-14: Photograph of Correlator Output, with no Input, Showing Stray Light from Secondary Reflections

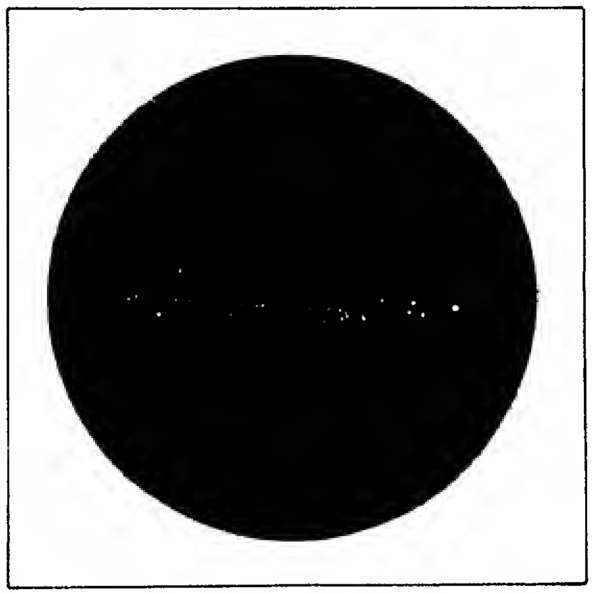


Figure 3-15: Photograph Showing Secondary Reflections as Viewed From an Off-Axis Position

secondary reflections that can be seen by the naked eye.

3.5 Reflections from Metal Surfaces Within the Relay Lens

The only experiments undertaken on this subject involved removing the metal stops and substituting black felt, and removing the baffling. With the removal of the jaws there was no longer a moving slit mechanism, so measurements were taken by making a single reading at the output, using a 65-300 cycle/inch aperture. This was augmented by a series of photographs which proved, unfortunately, to be almost useless in interpreting the changes made. In short, despite several changes in baffling and zero-stops, there seemed to be no change in the noise output.

3.6 Film Granularity Measurements

Two measurements are of interest in relation to the noise contributed by film granularity. The first is the amount of noise contributed by a piece of film with the same overall density as data film; the second is the variation of granularity noise with film density. Some amount of noise must be tolerated, but if there is a significant difference among the various densities, then a different exposure might be used on the recording film to minimize the noise. Leith[2] ignored this effect in his treatment of signal-to-noise considerations, although the article by Roetling[3] shows that this variation is significant, and furthermore that the noise itself can be modulated. This latter phenomenon has not been specifically investigated in this program, although some earlier work tends to confirm Roetling's hypothesis. It had been found that the data

---

[2] Emmett Leith, "Photographic Film as an Element of a Coherent Optical System", Photographic Science & Engineering, Vol. 6 #2, March-April 1962; pp. 75-80.

[3] Paul Roetling, "Effects of Signal-Dependent Granularity", JOSA, Vol. 55 #1, January 1965; pp. 67-71.

film could be satisfactorily correlated even when the bandpass in the frequency plane was limited to frequencies far above those nominally on the data film. The likely conclusion is that the high-frequency noise had been modulated.

Figure 3-16 shows traces before and after a piece of film of overall density 0.94 was placed in the input. (Earlier it has been determined that the average density of data film was 0.8 to 1.0.) The noise level was increased by a factor of one-half.

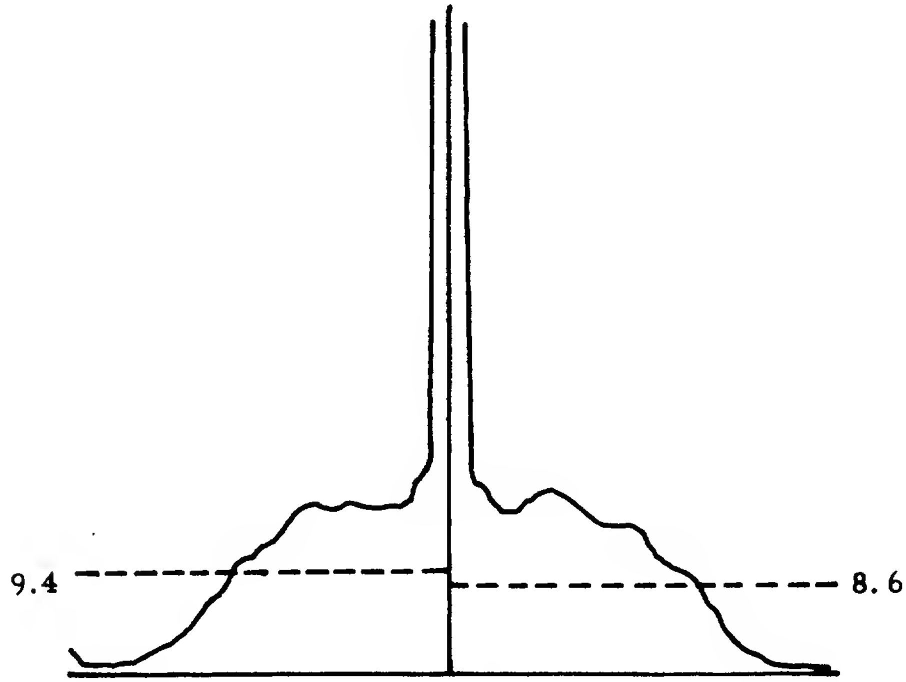
Table 3 shows the noise levels measured with films of various densities in the input. There seems to be no important variation, although Bayer[4] and others predict that there should be one. It seems likely that the film base

Film Density	Noise Level
1.86	13.2
1.55	13.5
1.28	14.2
1.18	13.0
0.94	12.3
0.60	11.7
0.34	12.4
0.13	14.4
0.08	13.3
no input	8.6

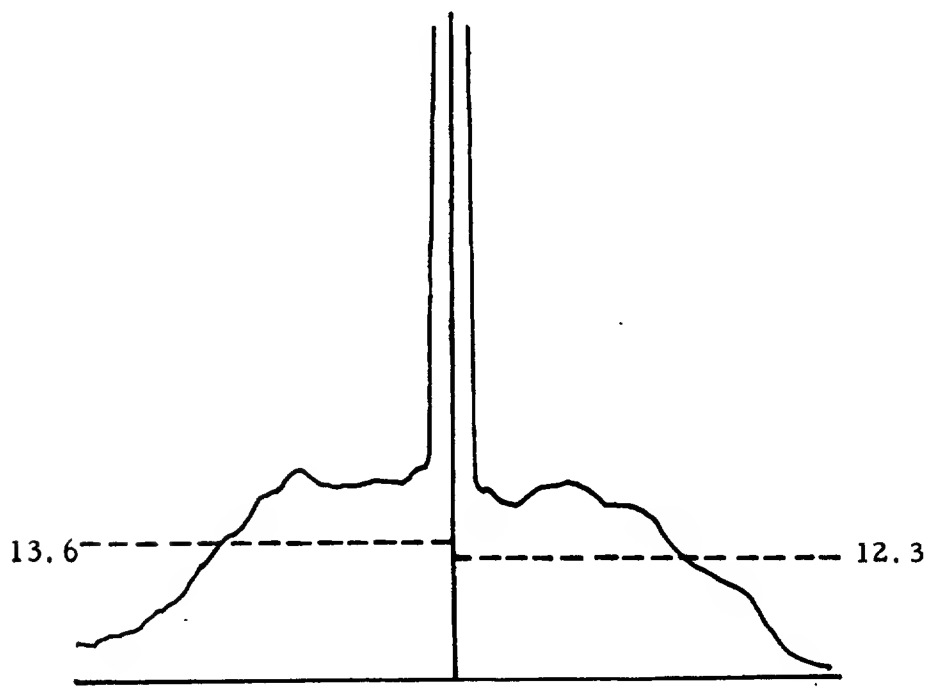
Table 3: Variation of Noise Level (Film Granularity) with Density

accounts for a considerable amount of noise itself, for 0.08 is a very low density, yet the noise it produces is comparable to the noise produced by greater densities.

[4] B. E. Bayer, "Relation Between Granularity and Density for a Random-Dot Model", JOSA, Vol. 54 #12, December 1964; pp. 1485-1490.



(a) Trace of stray light with no input.



(b) Trace of noise and stray light with an input film of overall average density 0.94, approximately that of data film.

Figure 3-16: Results of Inserting Film in System

Section 4.0

RECOMMENDATIONS TO REDUCE STRAY LIGHT IN THE PROCESSOR

4.0 RECOMMENDATIONS TO REDUCE STRAY LIGHT IN THE PROCESSOR

The 9015 Processor is currently in use at the Westinghouse plant in Baltimore. It is being operated by Itek engineers in support of the F101 flight test program. The stray light in the optical system of the Processor creates undesirable streaks and background fog on the output map film. Itek and Westinghouse engineers have re-analized the possibility of improving the stray light characteristics.

In examining the situation, a few of the possible improvements were found to be feasible. All of the improvements have been previously considered but new emphasis has been placed on the effort by the current program and new information is available from the stray light study reported in the previous two chapters. These new inputs have lead to the following recommendations:

(1) Refinish the platen glass surfaces periodically. Initially this will require the fabrication of spare platens. The new platen tray installed early in 1965 makes this periodic changing of the glass feasible.

(2) Resurface any lens surfaces that have become badly scratched.

(3) Remount the entrance slit in a manner that will allow for better access to the back of the slit.

This will enable better devices to eliminate reflected light from the back edge of the slit.

(4) Re-align and/or re-make a blocking slit at the interference filter. This blocking slit is intended to eliminate secondary images from inter-surface reflections in the interference filter.

(5) Filter the immersion fluid. This will require a new input platen tray as well as a pump, filter, and suitable control valves.

(6) Examine the possibility of improving the light trap characteristics of the zero stop in the relay lens.

Items 1, 2, 3, and 5 have been engineered and cost data sent to Westinghouse for their consideration. The Itek field engineer pursued item 4 and has solved the problem. The field engineer feels that the zero order stop (item 6) is causing very little problem at present, so no firm recommendations have been made.

Section 5.0

FILM CONSIDERATIONS

5.0 FILM CONSIDERATIONS

Over the past five years the choice of film for the hologram record has been continually reviewed. It was realized at the outset that the linearity and graininess of the film would have a marked influence on the quality of the correlated map film, but there was inadequate theoretical or experimental knowledge to ascertain the effect in detail. As the program continued, this knowledge gradually was acquired, and the sensitometry was gradually modified and standardized to give the best results. Various specific tests to determine the optimum sensitometry usually gave improved insight, but showed that there was little or nothing to be gained by changing the current procedures. This was partly due to the many problems encountered in the equipment which masked most small variations.

In late 1964 the equipment was improved to the point that most problems were either eliminated or at least well understood. It became obvious that some serious problems in the details of the image were still not solved*. A program to investigate the linearity of the system was started at SEI with some theoretical investigation on a computer. This effort clarified the film linearity question, and indicated that the hard limiting in the radar receiver might be causing more image problems than had been realized. In 1965 the radar receiver was modified and flown at low gain settings to check on possible

*For example, see Section 7.5 of the 9015 Project Final Report.

improvements. It was anticipated that if the increased linearity gave better results, the film linearity would become a serious obstacle to system optimization.

During the same 1964-65 period the system was working well enough for noise to become considered in detail. The grain of the data film is a source of noise that cannot be eliminated and therefore should be minimized.

For the above reasons, it became apparent that the time was again ripe for a film study. This study was undertaken by the Itek Photography Department. Their report is a part of this report, but is included as an appendix to expedite the publication.

The work was conducted as an unclassified program mainly to expedite the work and partly to make the information of general use. Mr. Kohler is cleared and is familiar with the 9015 equipment, he gave close supervision on the program. The 5401 film discussed in the Appendix is the one currently in use in the recorder. The choice of speed of at least 1.5 stops slower than 5401 is based upon the fact that the recorder lens could be opened one stop (at some loss in resolution) and the CRT brightness could be increased slightly if necessary. The study was limited to single film techniques because no continuous printers available will maintain adequate alignment.

Theoretical work at [redacted] in late 1964 finally established that the film STAT
characteristic that should be linear is the square root of the specular or "coherent" transmission vs. the strength of the video signal*. This characteristic, as well as the density vs. log exposure and diffuse transmission vs. exposure is plotted for many of the promising films. In general, the curves

*This was not a new discovery, but it was the point at which the issue was clearly resolved for all concerned.

are somewhat different but the region of linearity is not significantly changed.

The findings of the photographic work can be summarized as follows:

There are a few other films that could be used, but none have a clear advantage over 5401. The improvements in granularity are small and are gained at the cost of a small loss in speed. These results, coupled with silver halide photographic theory, indicates that there is little or nothing to be gained by changing films.

An investigation into reversal processing techniques gave considerable promise. A major problem arises in that a weakly exposed film normally gives a dense image when reversed. This is not acceptable in the correlator, so methods must be found to give a low density film. The first method investigated reduced the final image to obtain a high transmission. This was found to work poorly. A second method depends on adding an overall fog (or latensification) to the film. This process gives a dense negative which when reversed gives a light positive. This technique holds considerable promise, but the lack of time prevented a more thorough investigation.

In conclusion, the study indicates that the recorder should continue using 5401 film processed as at present. A study program to further pursue the possibilities of reversal processing should continue to establish the feasibility of such a technique.

Appendix

IMPROVING THE TRANSMISSION VS. EXPOSURE LINEARITY OF PHOTOGRAPHIC EMULSIONS

by

STAT

30 June 1965

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INTERNAL TECHNICAL REPORT PD-438

30 June 1965

PHOTOGRAPHY DEPARTMENT

IMPROVING THE TRANSMISSION VS. EXPOSURE LINEARITY OF PHOTOGRAPHIC EMULSIONS

by

[redacted]

STAT

[redacted] STAT

APPROVED [redacted] STAT

APPROVED [redacted]

Manager, Photography Department

1.0 INTRODUCTION

This report considers the selection and processing of films on three characteristics, the film speed, the film linearity, and the film grain. The work was done in the spectral region of basic blue sensitization of all silver halide films. The chief differences between the work reported below and the information normally available is the emphasis on linearity expressed as transmission vs. exposure rather than the usual "straight line portion of the D-Log-E curve". This definition is in closer analogy with the usual concept of linear response of detectors. For many modern optical experiments a laser is used, in this case the linearity is often related to the square root of the specular transmission vs. exposure. These two definitions usually give roughly similar curves, but results for some films have been measured and plotted both ways for comparison.

The films were exposed in an EG & G Sensitometer with a Wratten 48 blue filter. The density of each step was read on a MacBeth Densitometer (TD-100) and plotted as a D-Log-E curve and in some cases as a T-E curve. A few selected films were also measured on a Microdensitometer with an effective aperture of 24 microns diameter to measure the specular transmission and the $\sqrt{T_s}$ - E curve was drawn. The speed was determined by the exposure required to give a diffuse density of .6, the exposure values were normalized to make the 5374 speed equal to one.

The graininess of the film was measured and/or photographed for comparison purposes. In keeping with the interest in transmission rather than density, the graininess is expressed in terms of σ_T (RMS_T).

In making this study, two approaches were taken, the use of a negative and a reversal process. The goal of the negative process studies was to find a film-developer combination that had high speed, low grain, low fog, and a reasonably long $\sqrt{T_s}$-E response (approx. 10:1).

The studies with the reversal processing was also undertaken to achieve the above goals. The purpose in investigating reversal techniques, however, was based around tone reproduction theory which indicates that a reversal process would give improved linearity.

Although it was not possible to complete all aspects of the work required in the time period allocated, the results obtained to date were very encouraging. It definitely appears as though a reversal processing procedure could be developed which would yield much improved linearity and reduced granularity.

2.0 NEGATIVE PROCESS EVALUATION

The purpose of this portion of the study was to compare the speed, granularity and linearity of several candidate films with the control, 5401. The hope was to obtain a film with nearly the same speed, less grain, and significantly greater linearity than 5401.

2.1 EMULSION SPEED AND LINEARITY

Film speeds reported herein are the speed relative to Type 5474, which is called 1.0. The sensitometry has been done on an EG & G Sensitometer with a Wratten 48 filter. The films receiving the major emphasis in this study are,

Eastman Kodak Plus-X Aerographic Type 5401
Eastman Kodak, Television Recording Type 5374
Recordak Dacomatic Recording Type SO-266
Eastman Kodak Panatomic-X Aerial Type 4400 (now 3400)
Eastman Kodak Direct Positive Type 5246

Table 1b summarizes the data on all of the films initially evaluated. Table 1a gives the sources of information for the data on each film in Table 1b.

TABLE 1a: Sources of Information for Table 1b

Code	Source
A	Current Itek Test (K. Venier, E. Liberatore, R. Marcus)
B	Previous Itek Test (PD-61 - 316, D.I. Harvey)
C	Itek Film and Plate Data Book
D	Eastman Kodak's Tech Bits No. 3, 1964
E	Eastman Kodak's Kodak Films for Cathode-Ray Tube Recording
F	GAF Ansco Photographic Data Sheet "Ansco Hyscan"
G	Recordak Technical Representative, Mr. M. Schmuck

Film	Speed		RMS (D)		Conclusions
SO-105	0.007	A	0.004	C	Too Slow
8430	0.08	A	0.020	C	Too Slow
4404	0.09	A	0.023	C	Too Slow
SO-243	0.13	A&B	0.016	C	Too Slow
SO-206	0.22	A			Too Slow
5427	0.50	A&B	0.043 in DK-50 0.037 in D-76	C	Too Slow
5374	1.00	STD.	0.042 to 0.053	E	BORDERLINE SPEED
4400	1.8 1.7	A B	0.052	C	POSSIBILITY
5305	2.1 3.6	A&B E	0.042 to 0.053	E	POSSIBILITY
Ansco Hyscan	2.7	B	0.065 ($\bar{D}$ = 0.7)	F	Too Grainy
SO-266	1.0 3.6	A G	0.03	A	GOOD POSSIBILITY
5246	2 - 3	A	compares visually with 4400	A	GOOD POSSIBILITY
Plus-X 5401 4401	3.2 5.6	A	0.05 to 0.06 0.088	A C	STANDARD
2474	5.6 5.0	A D	0.068 to 0.087	D	Too Grainy
2490	7.0	D	0.053 to 0.068	D	Too Grainy
2492	12.5	D	0.068 to 0.087	D	Too Grainy
2494	16.0	D	0.087 to 0.110	D	Too Grainy
2475	16.0	D	0.068 to 0.087	D	Too Grainy
Linagraph	18.0	D	0.068 to 0.087	D	Too Grainy
Tri-X Pan	30	B	0.140 0.087 to 0.110	C E	Too Grainy

TABLE 1b: Relative Speeds and Granularities for 20 films.

(Note: See text for spectral region and speed definition)

From this list of 20 films four films were chosen for more extensive speed and noise measurements. All of the films selected for additional testing have a granularity lower than 5401. Sensitometric evaluations were run on the four films in five developers, for times ranging from 2 - 15 minutes at 85°F. The 5401 control was processed in Versamat A for 3 minutes at 85°F. The five developers tested were;

1. MX-577
2. MX-579
3. D-19
4. HC-110 (1:15)
5. Versamat Type A

The purpose in conducting the developer evaluation in conjunction with high temperature was to attempt to obtain maximum emulsion speed in hopes of making the finer grained emulsion more nearly the same speed as the 5401. It was, however, found that any significant increases in speed were associated with an unacceptable increase in the fog level. In many cases the fog was greater than 0.6. When a negative is to be used in a normal printing process this much fog can easily be tolerated, since the printing time can be easily increased. However, for the purpose of this investigation, a high light transmission is desired; a fog level of 0.6 means that a maximum of 25% of the incident energy will be transmitted. With the requirement of maximum speed with fog level no higher than 0.3 to 0.4 (50 to 40 percent transmittance) there were only very slight differences in the speed obtained with each of the developers. Figure 1 is the resulting set of D-Log-E curves for the four films when each were processed in D-19, in comparison with Type 5401 processed in Versamat Type A. All of the films are approximately 1 1/2 stops lower than Type 5401. The exact speed change, though, is dependent upon the density level chosen to make the speed measurement. Therefore, it is difficult to give a more precise speed rating when the data are presented in this form.

D-Log E Curves

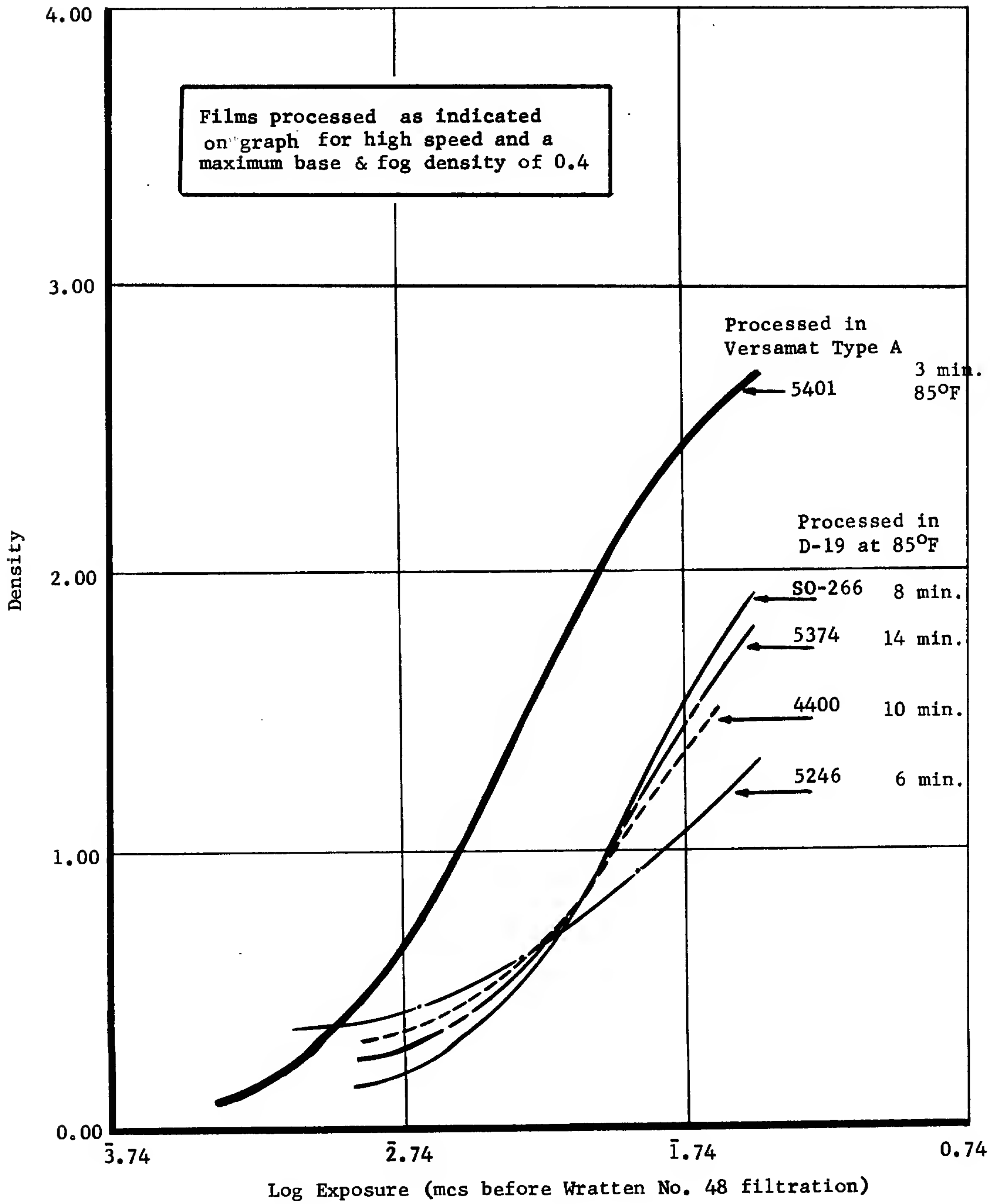

Figure 1

Figure 2 is a plot of the specular density D-Log-Ecurves for the five films. The basic change from the diffuse D-Log-E curves is the increase in contrast. Their relative speeds remain approximately the same.

The data for the Transmittance-Exposure curves in Figure 3 is the same as that plotted in the D-Log-E form of Figure 1. Type 5401 again is represented as the fastest film. The linear T-E region for Type 5401 is from approximately 0.02 to 0.06 mcs. This represents a linear T-E range of only 3:1. The remaining films appear to have longer T-E linear regions, but this is a false impression that is obtained from an absolute energy plot. For example, Type 5374 has a linear T-E response from 0.08 to 0.20 mcs. This is only a range of 2 1/2:1, less than that of Type 5401. Figure 2,therefore,is only good for comparing the absolute speeds of films. Type 5374 would require four times as much exposure as Type 5401 in order to expose the high transmittance end of linear portion the T-E curve. Type 5246 has a linear region from approximately 0.02 to 0.10 mcs. This represents a linear response of 5:1, and is approximately the same speed as Type 5401. It has the disadvantage, though, of obtaining this speed at the expense of its maximum transmittance. The resulting transmittance range for Type 5246 is only from 25-30% to 40%. Type 5401 has a linear transmittance range from 35-40% to 70%.

In order to have a better picture of the relative lengths of the linear regions of these five materials, the data from Figure 3 has been normalized to a common speed point and plotted in Figure 4. The curves all cross at an arbitrary exposure of 100 , which is the normalized exposure that would be required to produce a diffuse density of 0.6 (25% transmittance). It can be seen from this figure that there are only slight differences in the lengths of the linear portions of T-E curves for the different films. Figure 5 is a plot of the square root of the percent specular transmittance vs. exposure. Data for these curves are from the specular D-Log-E curves of Figure 2. The curves are similar in shape to that of the T-E curves of Figure 3.

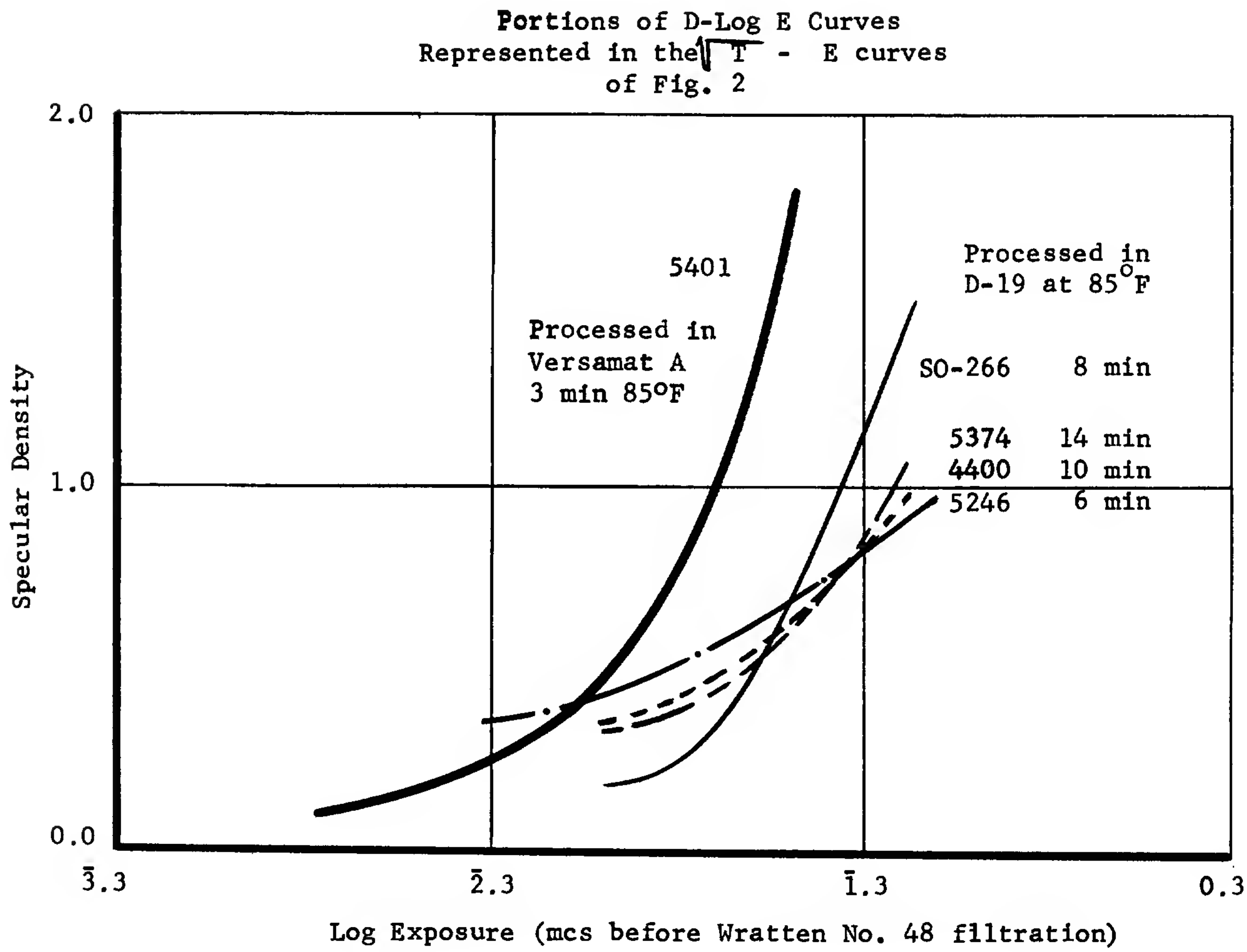
Portions of D-Log E Curves
Represented in the √T - E curves
of Fig. 2
2.0
1.0
0.0
Specular Density
5401
Processed in
Versamat A
3 min 85°F
Processed in
D-19 at 85°F
SO-266 8 min
5374 14 min
4400 10 min
5246 6 min
3̄.3
2̄.3
1̄.3
0.3
Log Exposure (mcs before Wratten No. 48 filtration)

Figure 2

Transmittance - Exposure Curves
for Five Eastman Kodak Films

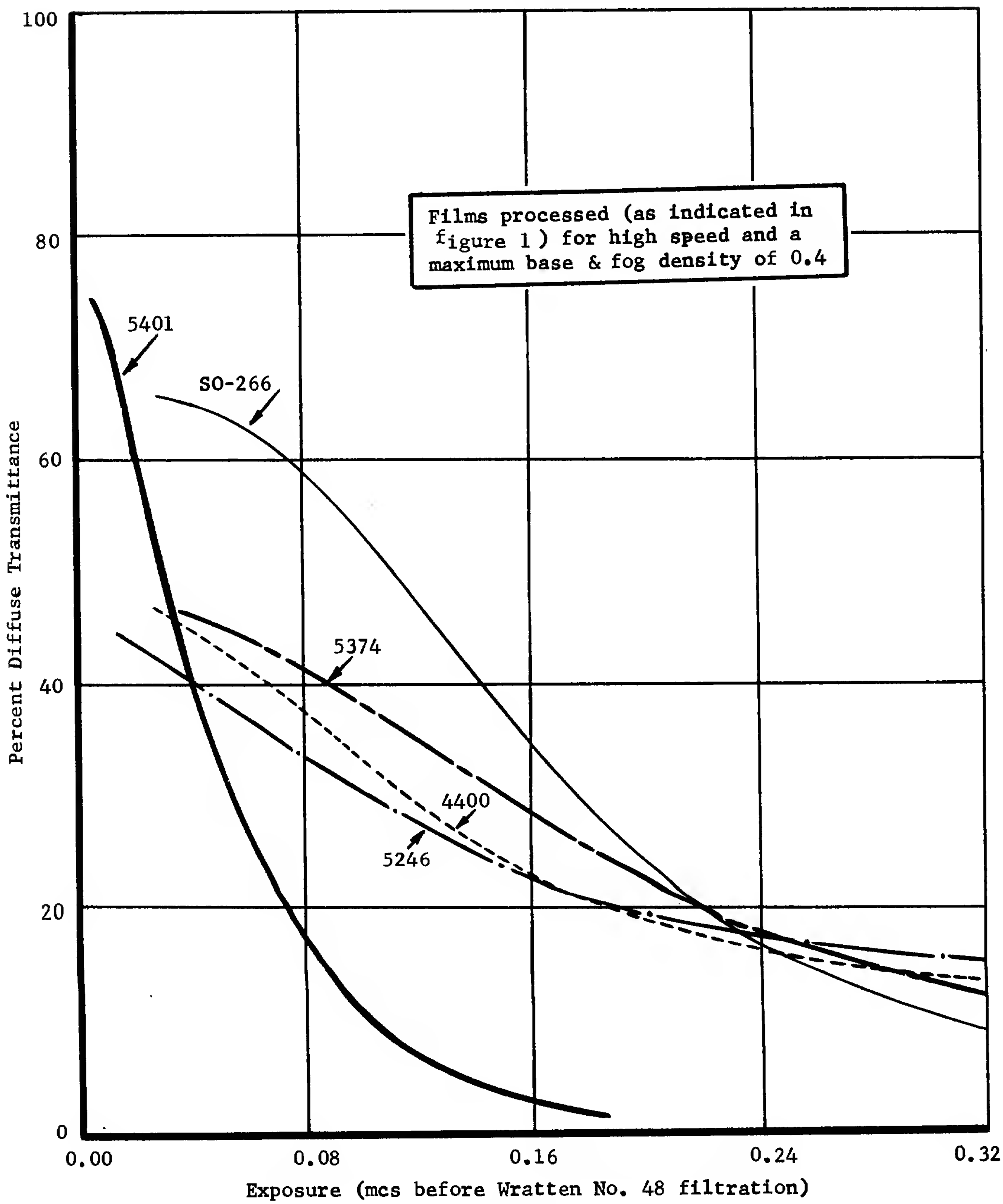

Figure 3

Relative Transmittance - Exposure Curves
for Five Eastman Kodak Films

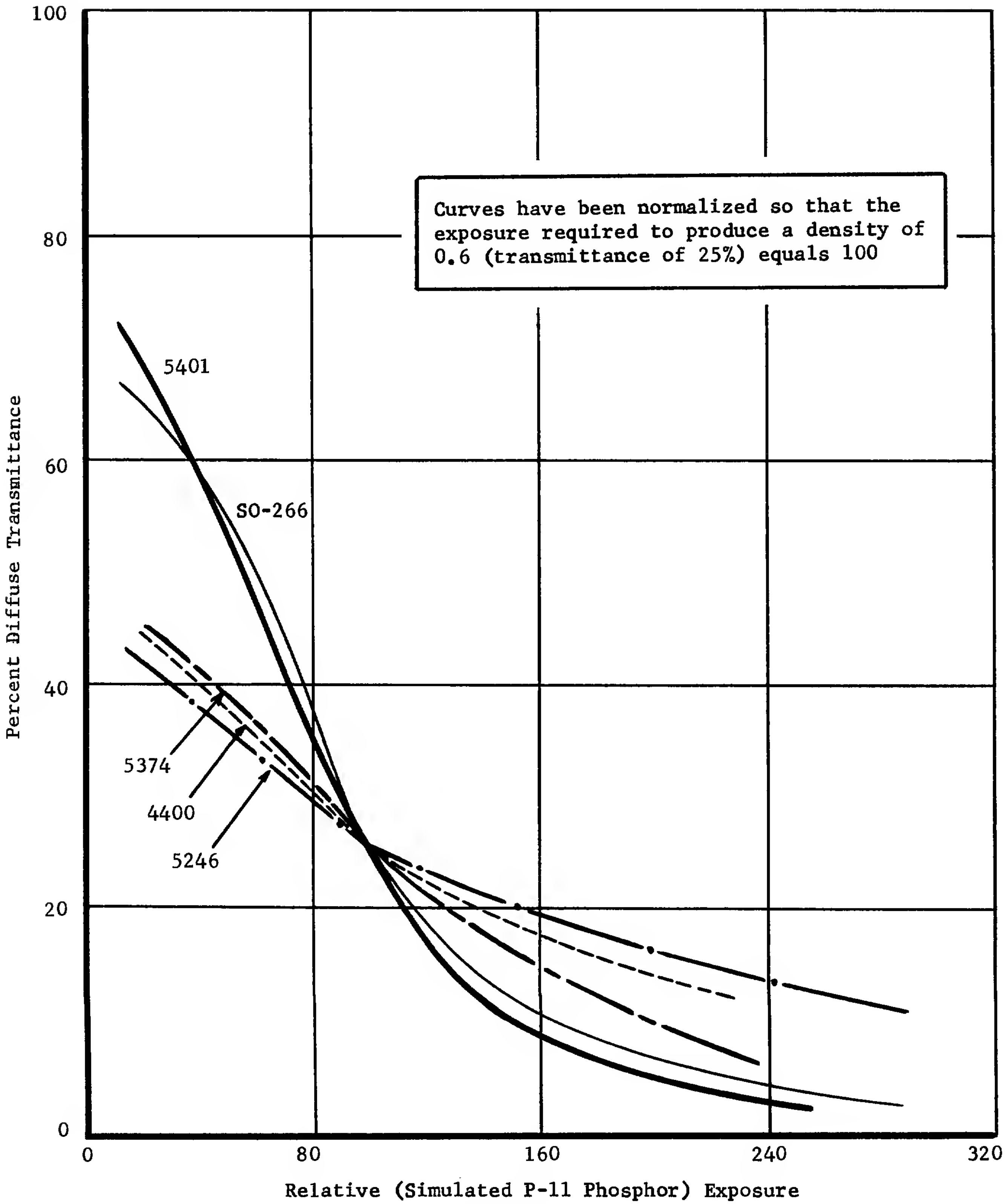

Figure 4

Square Root Percent Specular Transmittance vs Exposure Curves
For Five Eastman Kodak Films

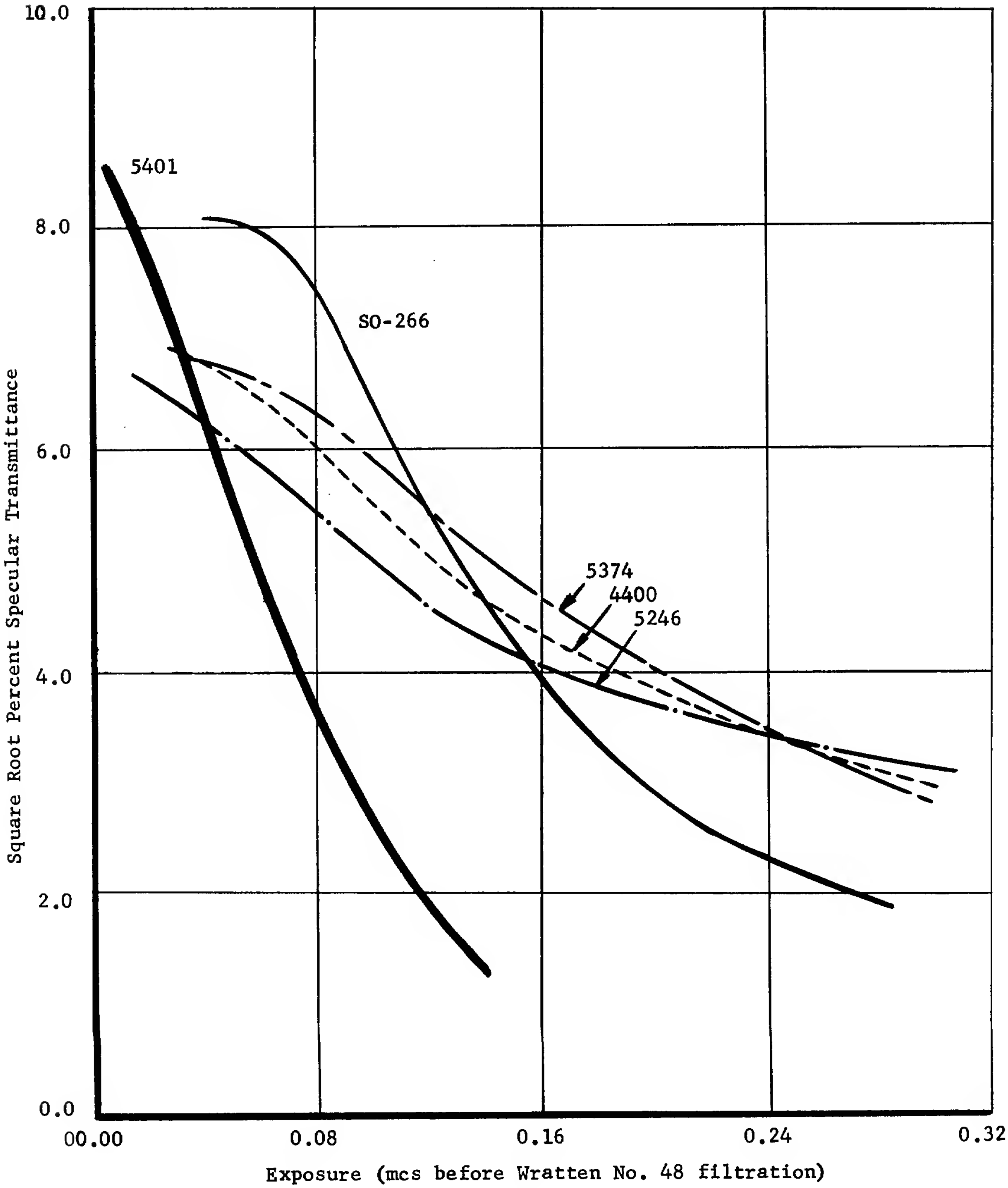

Figure 5

2.2 NOISE MEASUREMENTS

The quantitative noise measurements presented are in terms of the RMS fluctuations in transmittance through a uniformly exposed and processed film sample as measured with a 24μ aperture. Since our granularity computer measures RMS fluctuations in terms of density, the following approximation [1] was used in order to obtain RMS (T).

$$\sigma_T = \frac{(\sigma_D)\ (\bar{T})}{0.434}$$

Since this equation is only an approximation, a test was made to determine its validity. Agreement between the direct calculation of RMS (T) and the conversion using this approximation from RMS (D) was found to be within 2% for a density level of 0.6. This was felt to be sufficient so that the RMS (T) values could be obtained with our granularity computer.

Figure 6 is a plot of the percent RMS transmittance fluctuations vs. the average transmittance. As expected, the finer grained the film, the less the RMS (T). The ordinate of this graph is the one-sigma (68%) variation in transmittance that will occur when a uniformly exposed and processed film sample is traced on a microdensitometer with an effective 24 micron diameter aperture. At an average transmittance of 25%, there will be a one-sigma variation in transmission due to the grain structure of the film of:

1%	-	for TV Recording, Type 5374
1.3%	-	Dacomatic, Type SO-266
1.6%	-	for Panatomic-X Aerial, Type 4400
1.7%	-	for Plus-X Aerographic, Type 5401

Data for Direct Positive, Type 5246, is not available at this time. A visual examination of the samples for Type 5246 places it in a class with Type 4400.

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[1] J. H. Altman, The Measurement of RMS Granularity, Applied Optics, V3, N1, January 1965, Page 35.

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RMS Transmittance vs Net Transmittance

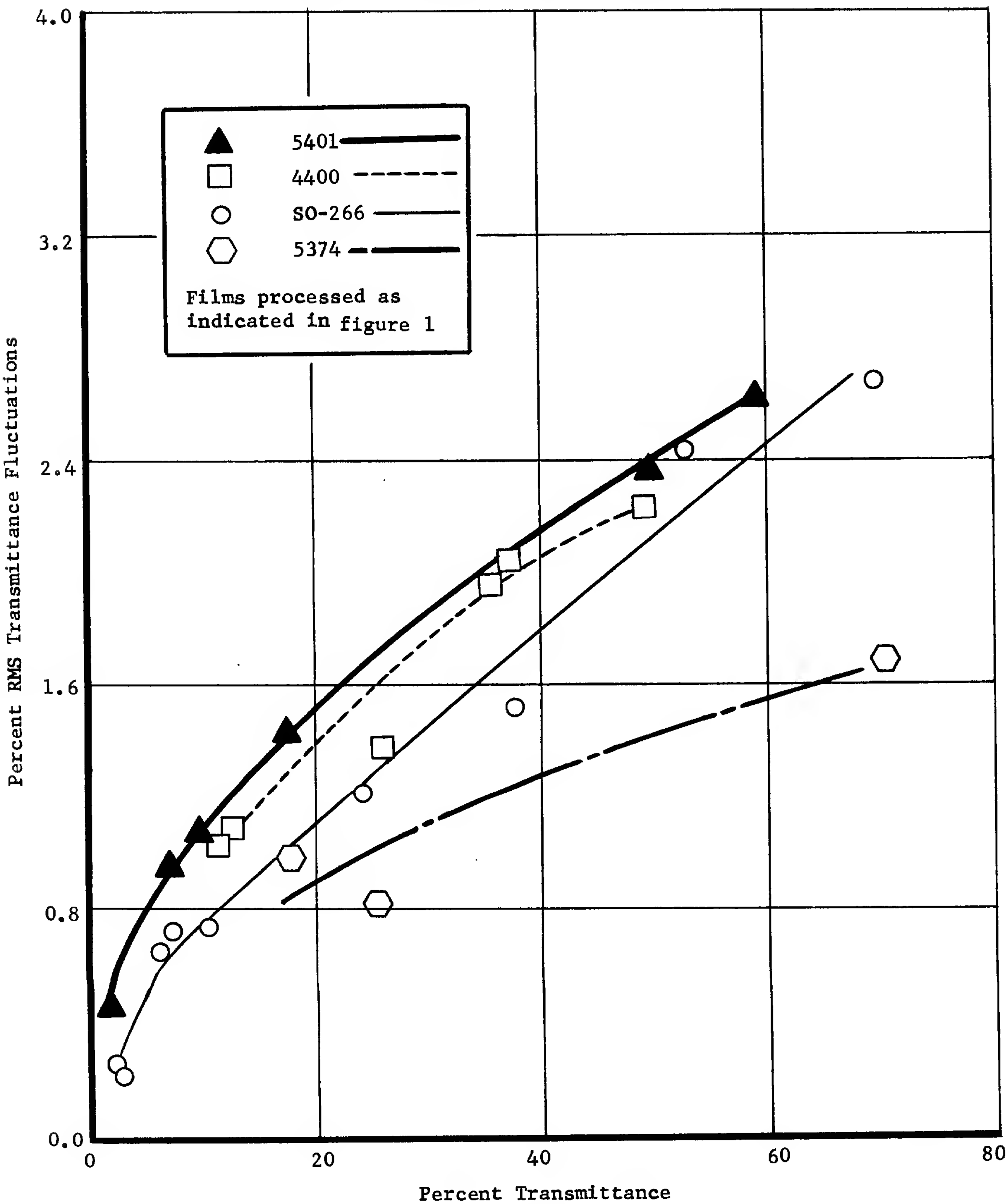

Figure 6

290X Photomicrographs of E.K. Types 5401 & 5374 Granularity Samples. Processing as Indicated in Fig. 1

Gross Density = 0.6

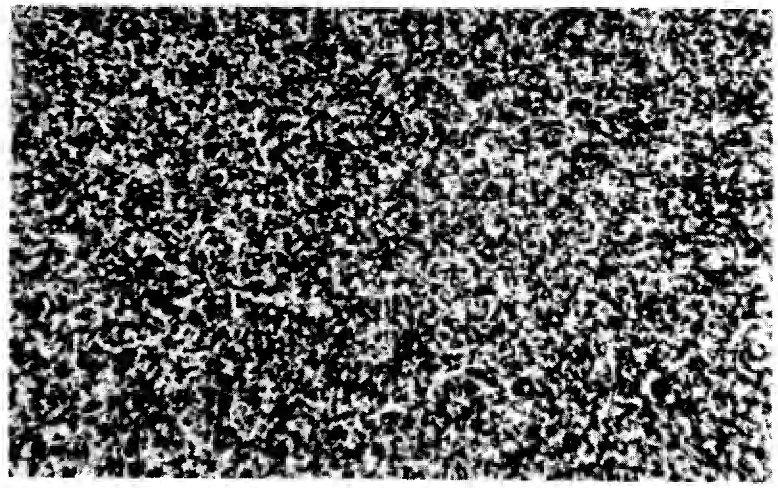

Figure 7a

Type 5401

RMS(T) = 1.7%

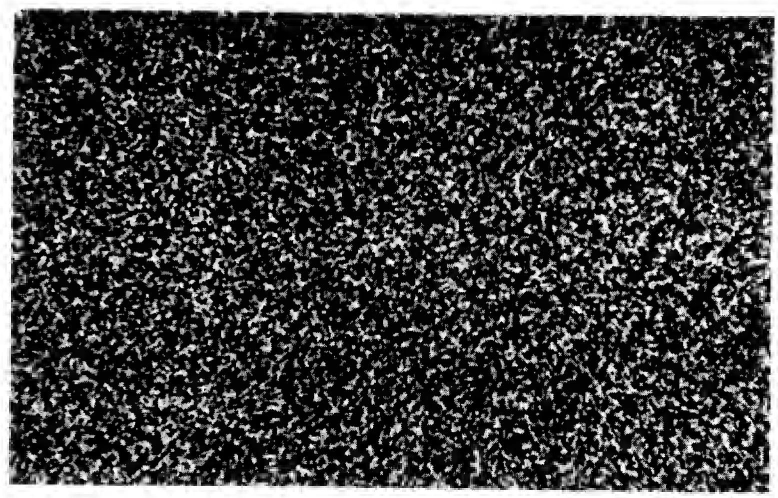

Figure 7b

Type 5374

RMS(T) = 1.0%

In order to "see" the relation between these values, Figure 7a and 7b contains photo-micrographs of the uniform patches of 25% diffuse transmittance for the extremes in RMS(T) encountered, Types 5374 and 5401. Here the improved graininess of Type 5374 is evident. But, Type 5374 is a factor of a 4 slower than Type 5401.

2.3 CONCLUSIONS--NEGATIVE PROCESS

None of the films tested are satisfactory for replacing the film currently used as the control. All have finer grain, but at the cost of speed. None have a significant improvement in their linear T-E response.

There is a reason to believe that no film will be found that has its blue sensitivity equal to Type 5401, and has significantly finer grain. Since the exposing radiation is in the region of the basic sensitivity of silver halide, the sensitizing dyes in Type 5401 or any other film are of no significant help. In fact, the addition of sensitizing dyes can lower the emulsions inherent sensitivity. This effect, though, is generally small. The basic speed determining factor is the inherent sensitivity and size of the silver halide grains. Since most emulsions today are a balance of the proper halides for optimum speed, the differences in their inherent sensitivity will be small. The determining factor, then, is the size of the grains themselves. Since a larger grain will have more surface area, the probability of being struck by an incoming photon is greater. Thus, the faster film (i.e. Type 5401) has the larger grains, the higher speed, and the higher granularity.

3.0 REVERSAL PROCESSING

Two films were chosen for the reversal process testing Type 5246 and Type SO-266. Both are available in 9 1/2 inch widths (Type 5374 is not) and both have finer grain than Type 5401. The basic reversal process used is listed in Table 2. Depending on the application, the desired response may be linear in terms of T vs. E or $\sqrt{T_S}$ vs. E. When one is linear, the other is not. The figure below indicates their relationship. The desired transmittance should range from 10 to 90 percent over this linear region.

The reversal process for both films resulted in T-E and $\sqrt{T_S}$-E curves that had possibilities of becoming linear over an exposure range of approximately 15:1. Two steps were taken in an attempt to make the curves more closely approach those of Figure 8; reduction of the positive and latensification during initial exposure.

Simulated T - E and $\sqrt{T}$ - E Curves

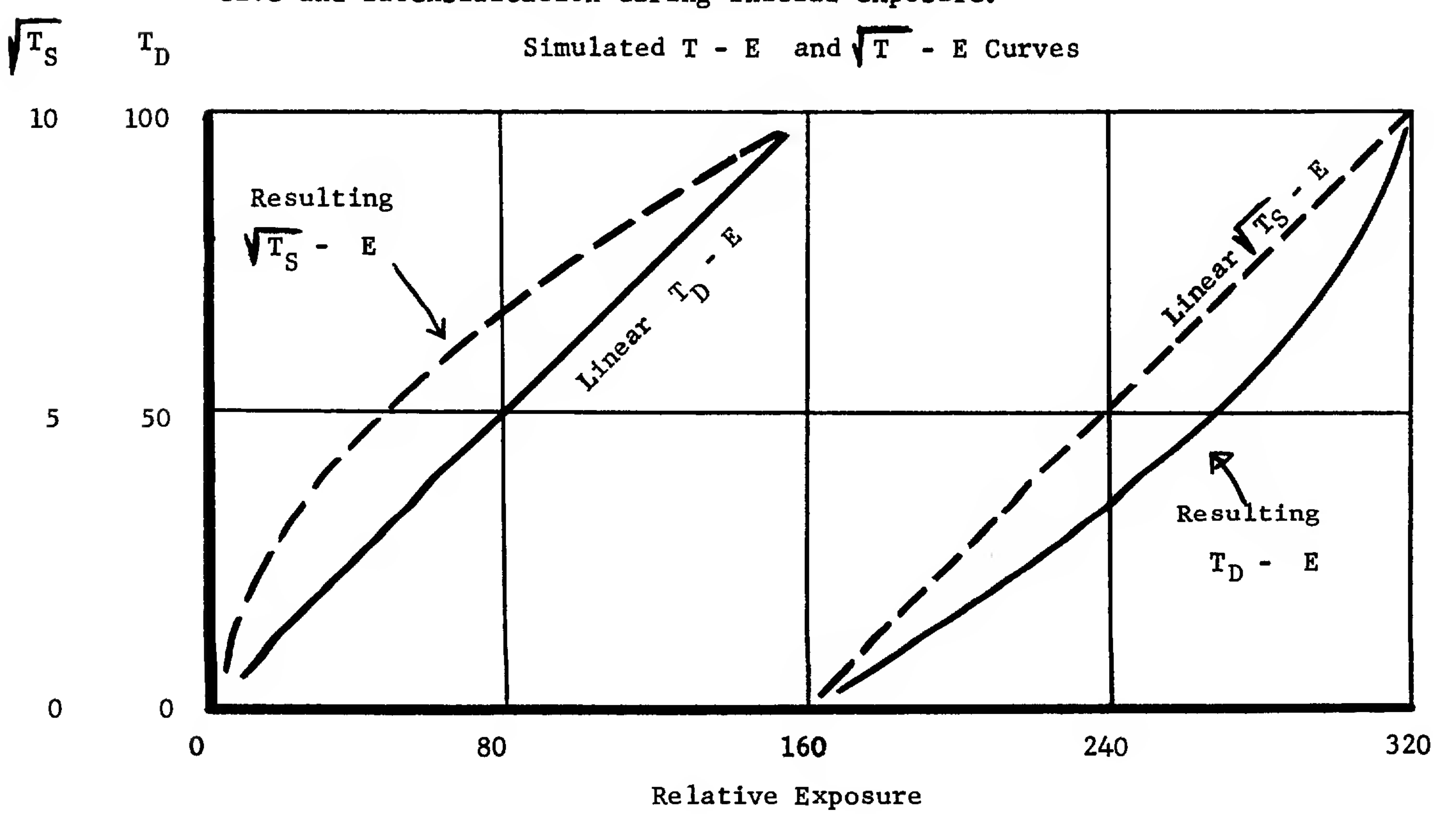

Figure 8

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TABLE 2a

Formulas for Reversal Process

Developer	UFG (Proprietary developer)	Twice normal conc.
	Potassium Hydroxide	22 g
	Potassium Thiocyanate	12 g
	Water to make	1.0 liter
Stop Bath	2% Acetic Acid	
Bleach	Potassium Dichromate	20 g
	Sulfuric Acid (Conc.)	25 ml
	Water to make	1.0 liter
Clear	Sodium Sulfide	100 g
	Water to make	1.0 liter
Re-Developer	(1) Kodak D-88 + 1 g/1 KCNS	
	(2) Kodak D-23	
Stop	2% Acetic Acid	
Fix	Kodak Acid Fixer	

TABLE 2b

Reversal Processing Times

Processing Steps (at 68°F)	
A. Developer	10 minutes
B. Stop	15 seconds
C. Bleach	45 seconds
D. Rinse (Water)	15 seconds
E. Clear	45 seconds
F. Rinse	15 seconds
G. Re-Expose	2/10 second, 6 feet from a No. 2 photoflood
H. Redevelop	(1) 2 minutes
	(2) 3 minutes
I. Stop	15 seconds
J. Fix	30-60 seconds
K. Wash	10 minutes
L. Dry	

3.1 REDUCTION OF TYPE 5246 POSITIVE

Figure 9 shows the T-E curves of Type 5246 processed as both a negative (■) and a positive (□). It can be seen from this figure that the positive is almost linear over an exposure range of approximately 0.05 to 0.70. Though the bow in this curve is slight, it is a significant departure from linearity. By laying a straight edge on the positive curve the bow becomes more apparent.

The positive sensitometric strips were reduced in two reducers in order to increase the overall transmittance. Neither the proportional (Δ) or subtractive (O) reducers had a beneficial effect on the linearity of the T-E curve. The reduction process magnified the non-linearity of the curve, as well as adding a non-linear effect of its own.

The positive, represented in the $\sqrt{T_s}$-E graph of Figure 10 does not have as satisfactory a linear region as the T-E curve. Reduction of the positive has also had a negative effect on the linearity. Since granularity data is not available at this writing, photomicrographs have been prepared, Figure 11 allows a visual comparison to the systems graininess. The photomicrographs are of the steps in the sensitometric strip that have a resulting diffuse density of 0.6. It appears from these photomicrographs that the reversal process has resulted in a film sample that has finer grain when the material is processed as a positive instead of a negative. The theory behind this phenomenon is that the larger grains (having more surface area to collect incoming photons) are faster and are hence exposed first when the film is developed as the negative. When the film is chemically reversed, there are only the smaller grains left to form the final image. Therefore, the image is of finer grain than if it had been processed as a negative.

The positive that had been reduced has a finer grain structure than the negative also. But, it is difficult to tell from these photographs whether or not it is better or worse than that of the unreduced positive.

Since the linearity of the T-E or $\sqrt{T_s}$-E curve was not significantly improved, work with the reduction process was abandoned.

3.2 LATENSIFICATION OF TYPE SO-266

A series of latensification exposures were given to Recordak Type SO-266 before the initial image forming exposure. The results were, along with increased fog, an increase in the toe speed of 1/2 stop. Figure 12 is a plot of the T-E curves of the negative and positives with andwithout latensification. Though there is a high fog level in the resulting latensified negative, the latensified positive has a T-E response that is better than that of the non-latensified positive. The latensified positive has a higher transmission level and is closer to being linear over the exposure range of 15:1.

The ordinate of Figure 13 is a square root of the specular transmittance of Type 266. The curves follow the same trend as those of Figure 12, though they do not appear to be as close to linearity.

Photomicrographs of the grain structure (Figure 14) of Type SO-266 were of steps on the sensitometric strip that received equal exposures, since the curves cross at this point. It is difficult to see any improvement in the granularity, but both are considerably finer grain than Type 5401 (Figure 7a). At this time there is no quantitative data available for a direct comparison.

3.3 DISCUSSIONS AND CONCLUSIONS OF REVERSAL PROCESS

Figure 15 is a plot of the best linear T-E responses obtained with these two films in the reversal processes. There are two distinct regions of linearity in both curves, each being over a range of approximately 4:1. These curves, when plotted as $\sqrt{T_s}$ vs. E as in Figure 16 lose their two linear regions. The optimum $\sqrt{T_s}$ - E response for the reversal process is the dashed line between the two curves.

The desired D-Log-E curves for the linear T_D- E and $\sqrt{T_s}$ response are plotted in Figure 17 and 18. The changes in the D-Log-E curves do not appear too difficult to accomplish. With continued laboratory work it is possible that one of these films could result in the desired linear response.

Transmittance - Exposure Curves
for Eastman Kodak Type 5246

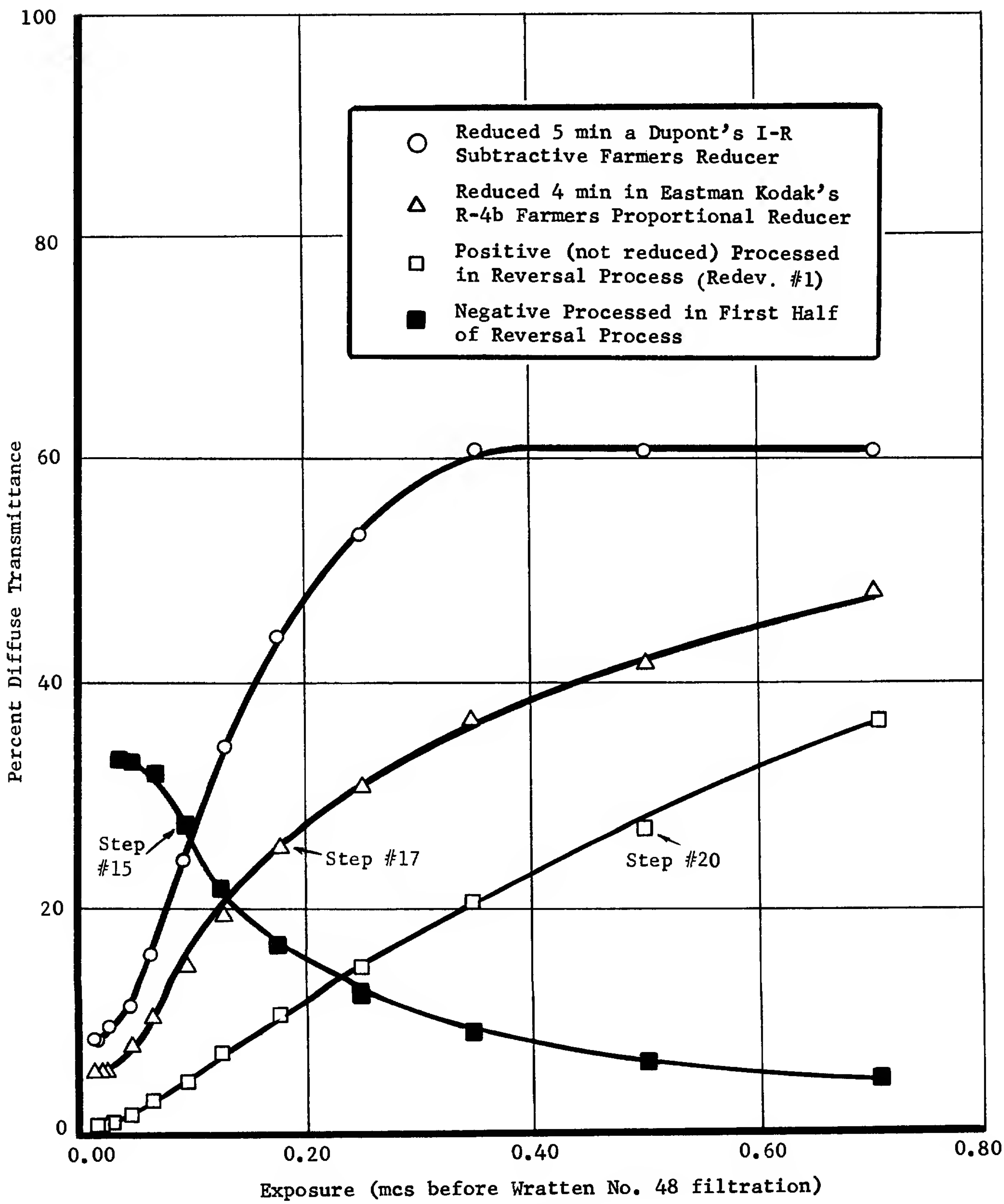

Figure 9

Square Root Percent Specular Transmittance vs Exposure Curves
For Type 5246 in a Reversal Process, Positive Reduced

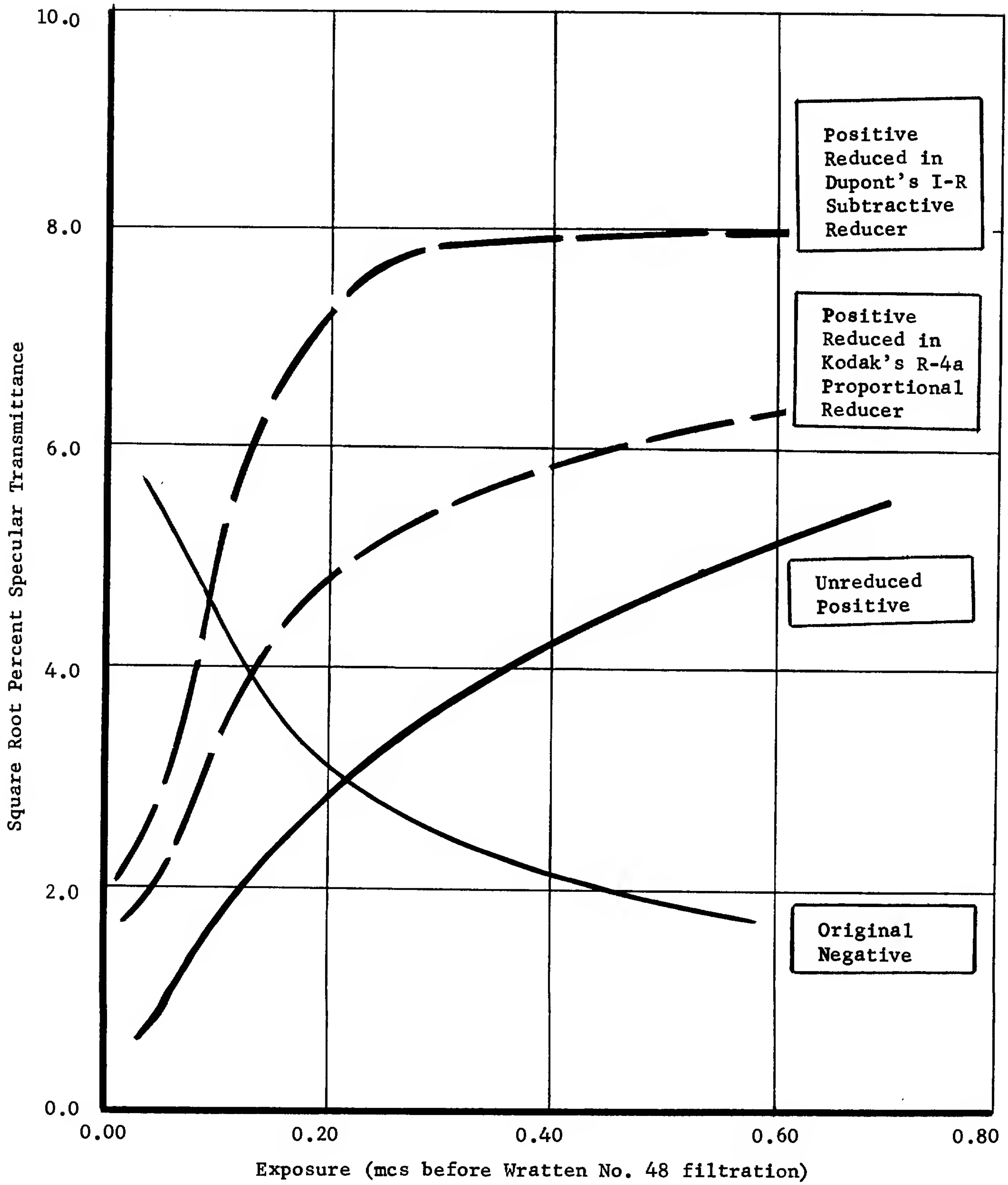

Figure 10

290X Photomicrographs of E.K.
Type 5246 Granularity Samples.
Processing as Indicated in Fig.7
Gross Density = 0.6

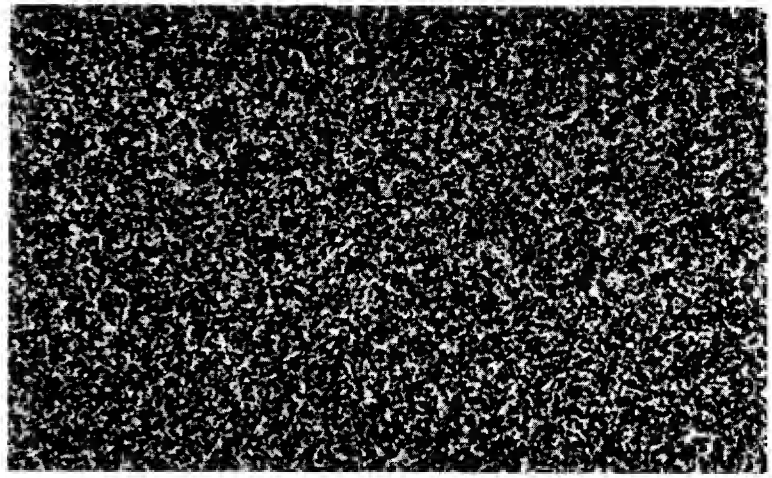

Figure 11a ■ Processed as a Negative
Step #15 in Fig. 9

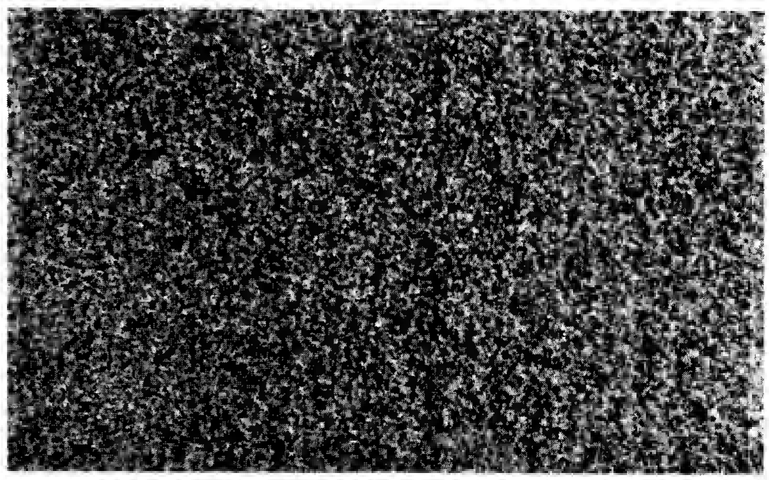

Figure 11b □ Processed as a Positive
Step #20 in Fig. 9

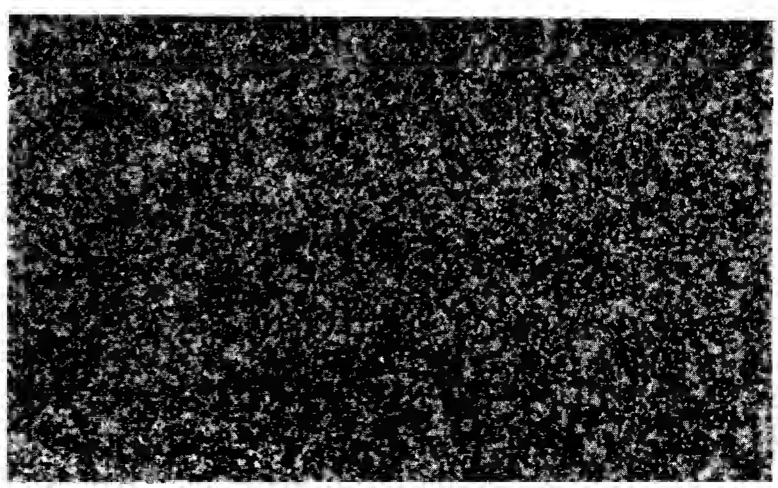

Figure 11c △ Processed as a Positive, then reduced
Step #17 in Fig. 9

Transmittance - Exposure Curves
for Recordak Type SO-266

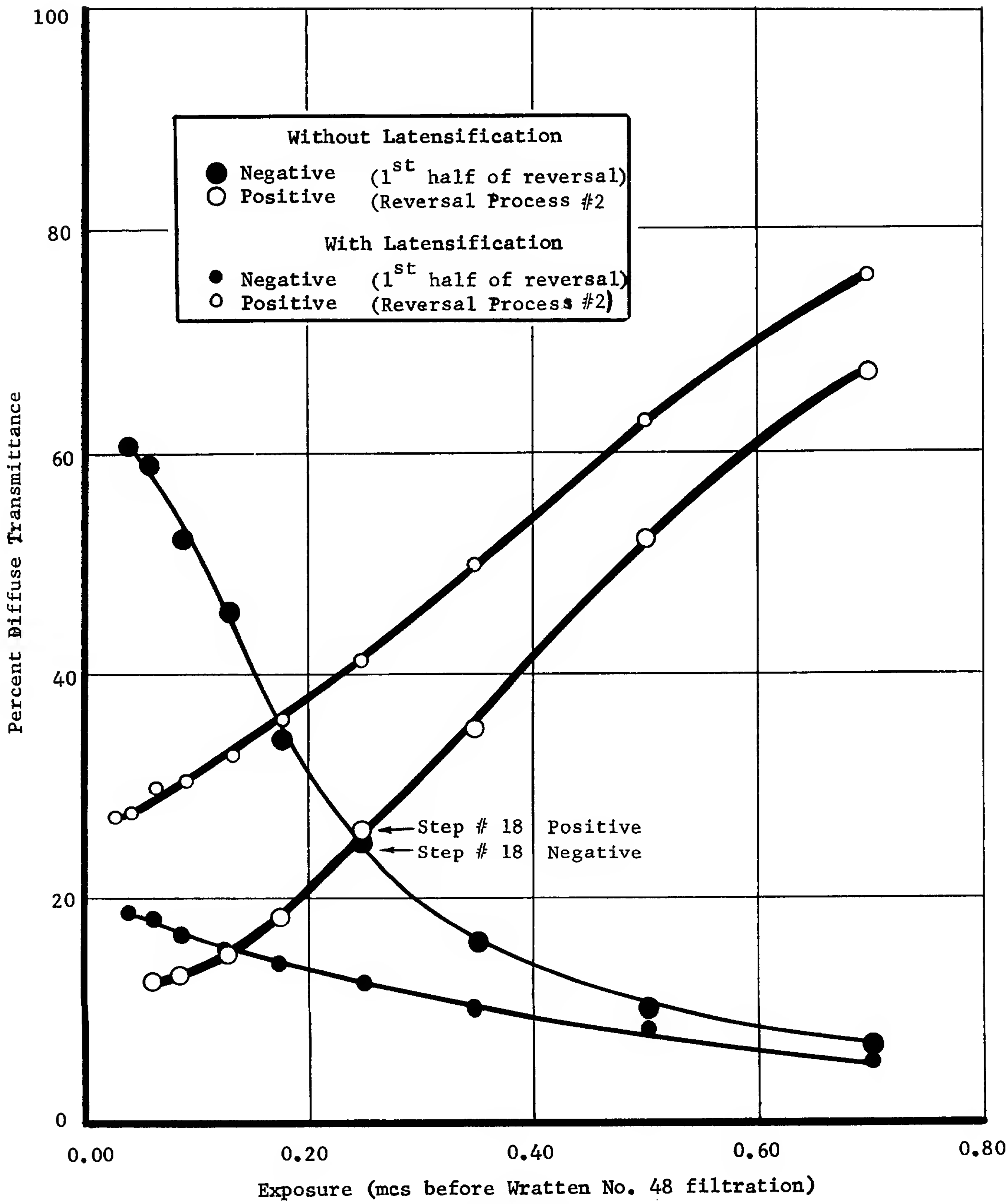

Figure 12

Square Root Percent Specular Transmittance vs Exposure Curves For Type SO-266 in a Reversal Process, With and Without Latensification

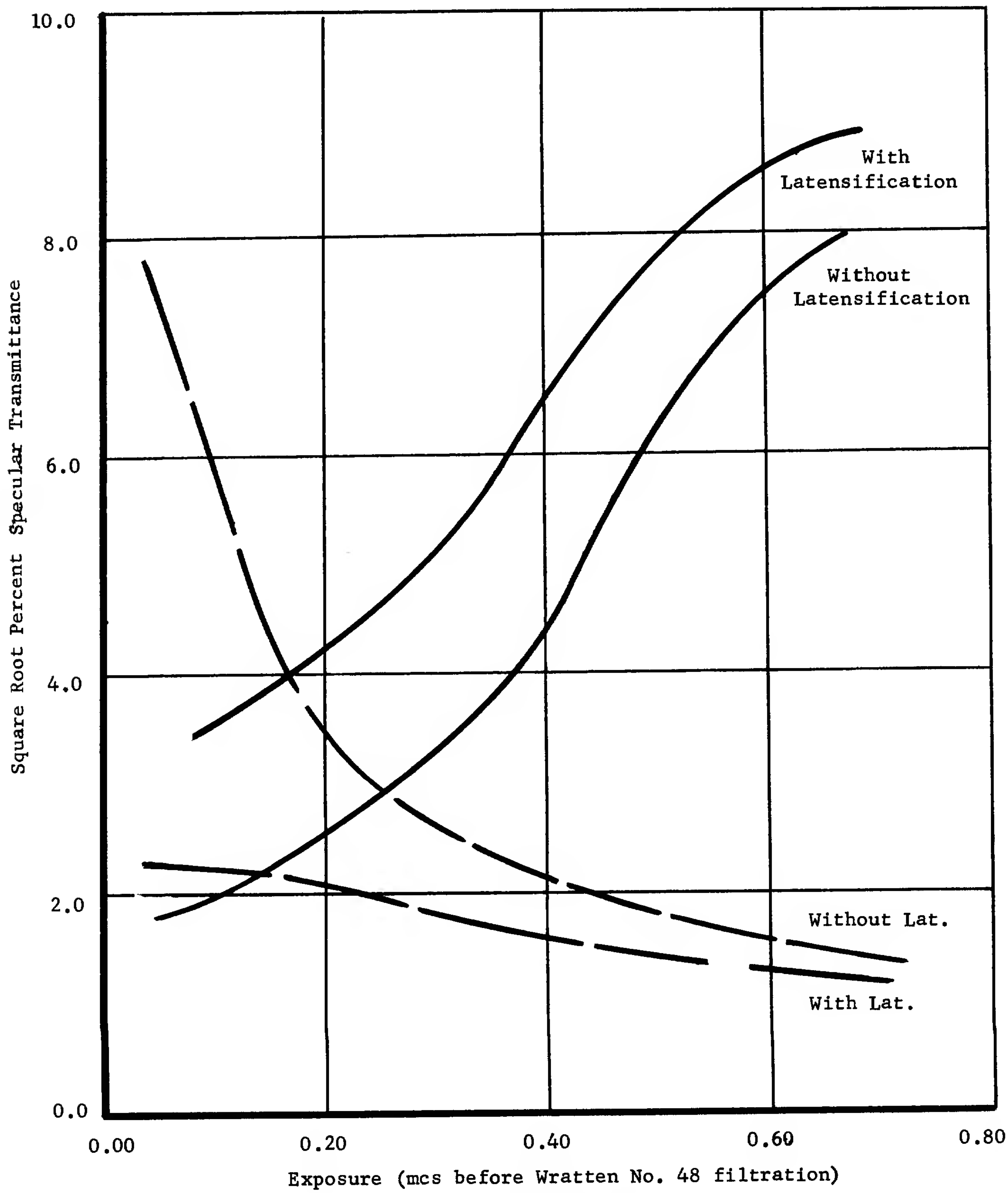

Figure 13

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290X Photomicrographs of Recordak Type SO-266 Granularity Samples. Processing as Indicated in Fig. 9

Gross Density = 0.6
Note: These Samples Recieved Equal Exposures

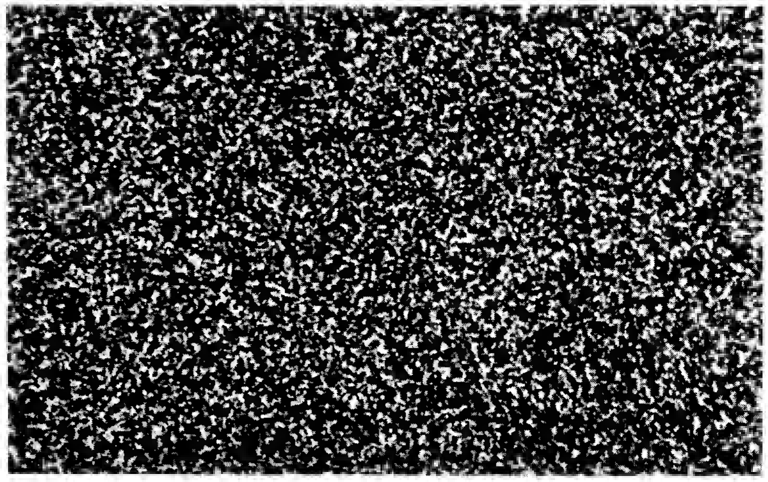

Figure 14a

● Processed as a Negative
Step #18 in Fig. 12

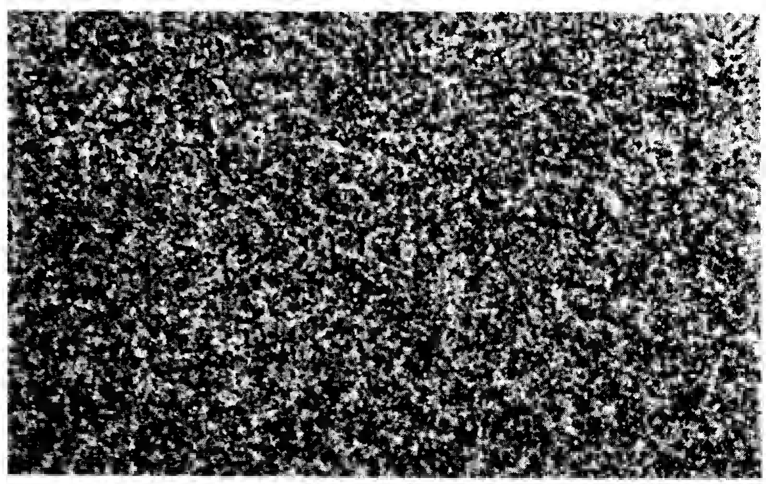

Figure 14b

○ Processed as a Positive
Step #18 in Fig. 12

Transmittance - Exposure Curves
for Eastman Kodak Type 5246
and Recordak Type SO-266

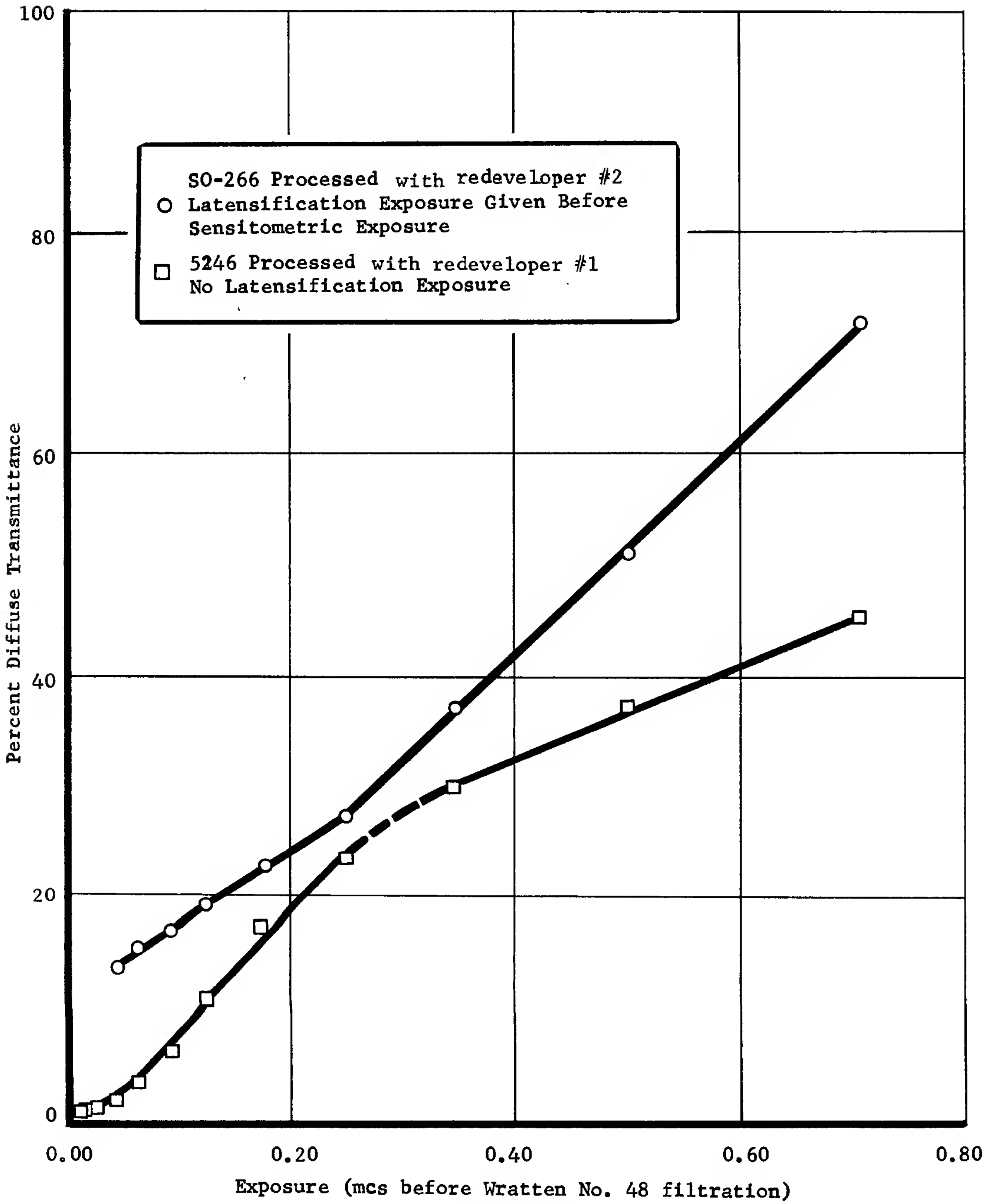

Figure 15

Square Root Percent Specular Transmittance vs Exposure Curves
For Two Eastman Kodak Films in Reversal Processes

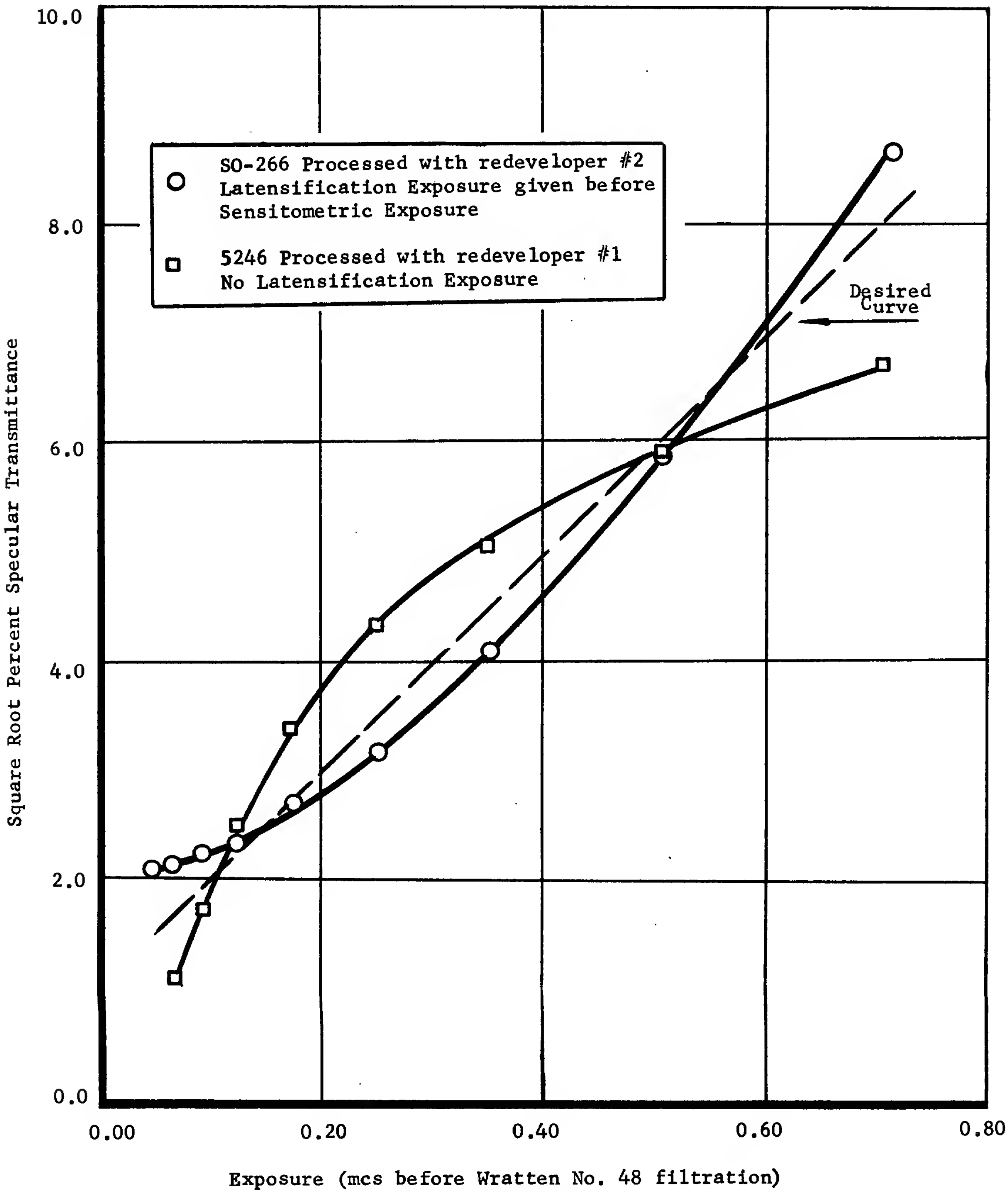

Figure 16

D-Log E Curves
for 2 Eastman Kodak Films

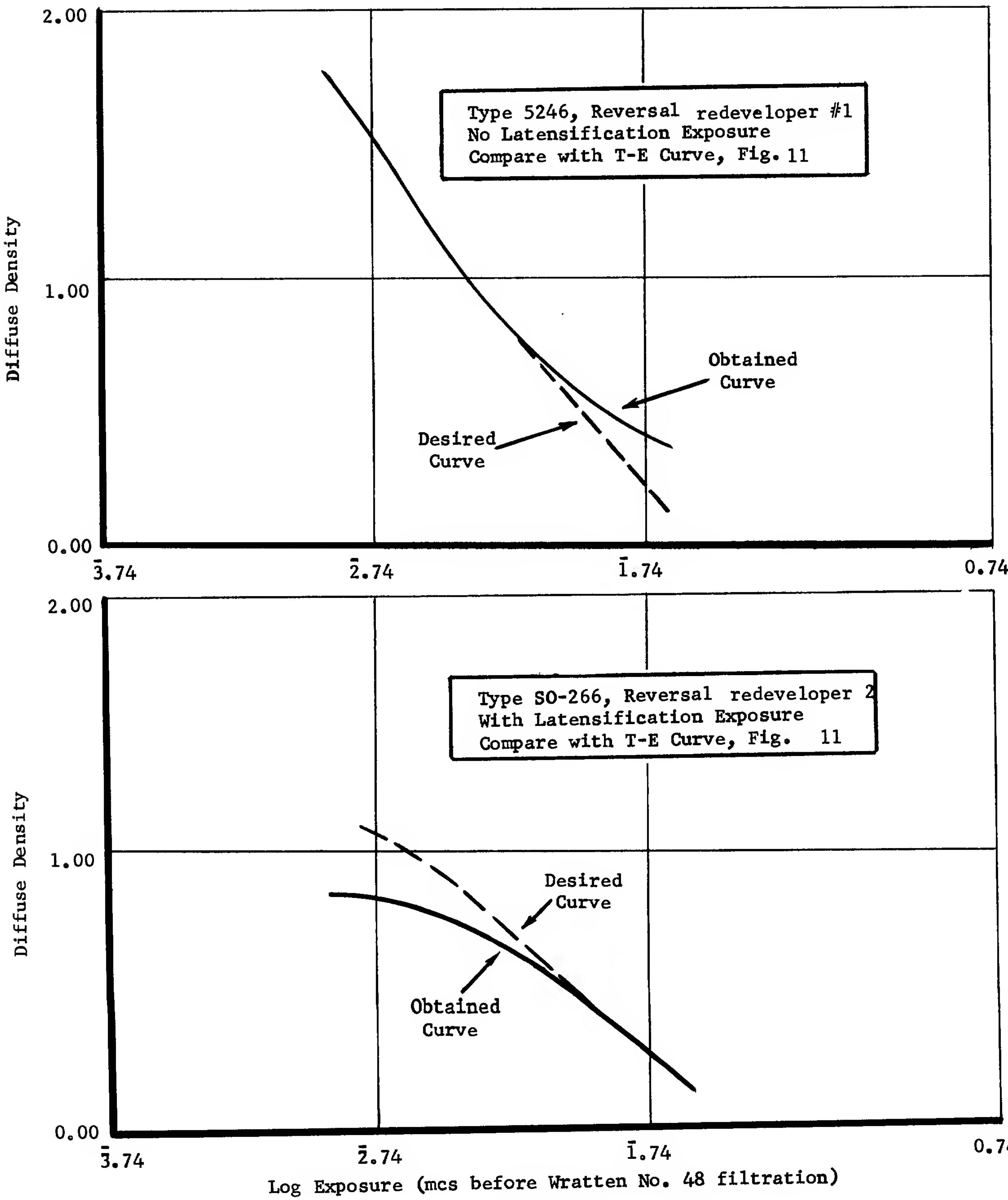

Figure 17

Portions of D-Log E Curves
Represented in the $\sqrt{T}$ - E Curves
of Fig. 2

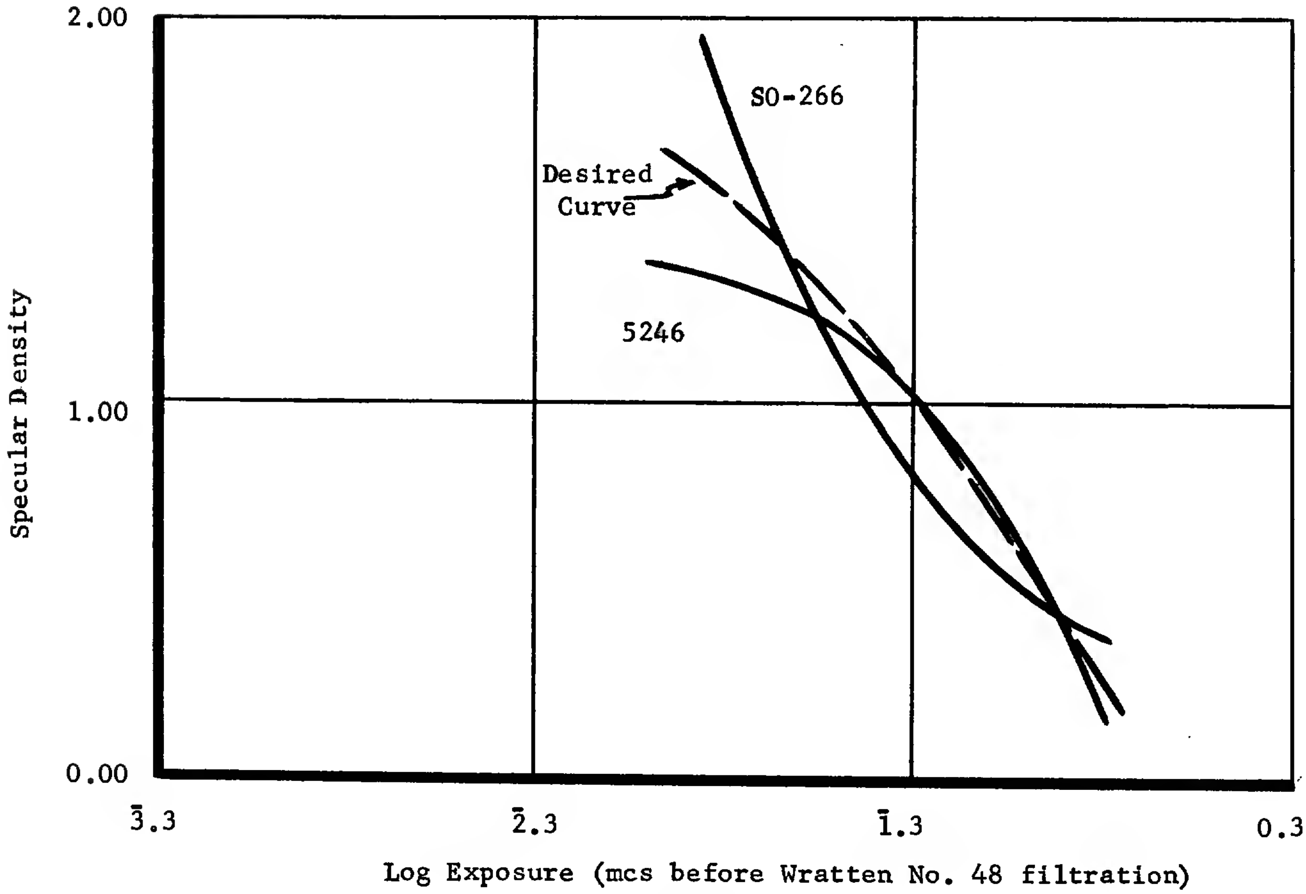

Figure 18